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Age and Origin of Base- and Precious-Metal Veins of the Coeur D'Alene Mining District, Idaho

R. J. Fleck, R. E. Criss, G. F. Eaton, R. W. Cleland, C. S. Wavra, W. D. Bond

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AGE AND ORIGIN OF BASE- AND PRECIOUS-METAL VEINS OF THE COEUR D'ALENE MINING DISTRICT, IDAHO

Robert J. Fleck
U.S. Geological Survey MS 937, 345 Middlefield Rd., Menlo Park, CA 94025

Robert E. Criss
Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130

Gail F. Eaton
Lawrence Livermore National Laboratory, Livermore, CA 94550

Rodney W. Cleland, Craig S. Wavra†, and William D. Bond
Sunshine Precious Metals Company, P.O. Box 1080, Kellogg, ID 83837

† Deceased

ABSTRACT

Ore-bearing quartz-carbonate veins of the Coeur d'Alene mining district yield $^{87}Sr/^{86}Sr$ ratios of 0.74 to >1.60 for low-Rb/Sr, carbonate gangue minerals, similar to current ranges measured in Middle Proterozoic, high-Rb/Sr rocks of the Belt Supergroup. Stable-isotope and fluid-inclusion studies establish a genetic relationship between vein formation and metamorphic-hydrothermal systems of the region. These extraordinary $^{87}Sr/^{86}Sr$ ratios require accumulation of radiogenic ^{87}Sr in a high Rb/Sr system over an extended period *prior* to incorporation of Sr into the veins by hydrothermal processes. Evaluation of the age and composition of potential sources of highly radiogenic Sr indicates that the ore-bearing veins of the Coeur d'Alene district formed within the last 200 Ma from components scavenged from sedimentary and metasedimentary rocks of the Belt Supergroup, the primary host-rocks of the district. These results are consistent with a Cretaceous or Early Tertiary age for these veins. Pb-Zn deposits that yield Pb isotope, K-Ar, and Ar-Ar results indicative of a Proterozoic age probably formed during deposition or diagenesis of the Belt Supergroup at 1350-1500 Ma, possibly as Sullivan-type syngenetic deposits.

K-Ar and Rb-Sr apparent ages and $\delta^{18}O$ values of Belt Supergroup rocks decrease southward from the Coeur d'Alene district toward the Idaho batholith, normal to the trends of metamorphic isograds, fold axes, foliation, and the major reverse faults of the district. Isoclinal folding, thrust faulting, high-temperature metamorphism, granitic plutonism, and regional-scale metamorphic-hydrothermal activity is documented in the region between 140 Ma and 45 Ma, but no similar combination of events is recognized for Late Proterozoic time. Combined with Sr results from the veins, the evidence strongly favors formation of the ore-bearing carbonate veins of the district by fluids related to a complex metamorphic-hydrothermal system during Cretaceous and/or early Tertiary time. Proterozoic Pb-Zn deposits were probably deformed, remobilized along younger structures, and incorporated into the younger hydrothermal deposits during this event.

INTRODUCTION

The present study was initiated to evaluate the age and source of mineralization in the Coeur d'Alene mining district, which remain controversial despite extensive mapping and structural, geophysical, geochemical, and isotopic studies that began over a century ago and continue today (Criss and Fleck, 1990; Criss and Eaton, 1998; Leach et al., 1998a,b). We present results of Sr isotopic studies of carbonate gangue from veins throughout the Coeur d'Alene district and discuss the constraints they place on the age of mineralization. Previous studies of the district provide the context into which these results must be placed.

Although the Proterozoic age of the Belt Supergroup was understood previously, Calkins subdivided the strata into recognizable mapping units in the Coeur d'Alene district (Ransome and Calkins, 1908). Obradovich and Peterman (1968) reported Rb-Sr and K-Ar ages of about 1100 Ma for equivalents of the Wallace and St. Regis Formations of the Belt Supergroup, but argued for an age of about 1325 Ma for equivalents of the Revett, Burke, and Prichard Formations. Recent U-Pb studies on zircon by Anderson and Davis (1995) and Aleinikoff et al. (1996) indicate that the majority of the Belt Supergroup in southeast British Columbia and western Montana is older than 1440 Ma, increasing the estimated age of Belt sedimentation. Units of the Belt Supergroup are host rocks for the vein systems of the Coeur d'Alene district and these ages must represent maximum ages for the mineralization.

After extensive mapping of the district and adjacent areas, Ransome and Calkins (1908) concluded that fracture systems related to emplacement of the Idaho batholith controlled the major ore-bearing veins. Additionally, they concluded "beyond reasonable doubt" that the most probable sources of the hot fluids responsible for ore deposition were underlying magmas related to the Idaho batholith, to which Lindgren (1904) assigned a late Mesozoic (post-Triassic) age (Ransome and Calkins, 1908, p. 137). Hershey (1912, 1916) provided detailed field studies linking ore deposition to the emplacement of monzonite stocks and felsic dikes, arguing persuasively that the intrusions were the direct cause of circulation of the fluids that dissolved the metals from the host strata (Hershey, 1916, p. 14). Hershey (1916, 1917) also described the complex relationship of the monzonite intrusive rocks to the ore bodies, detailing evidence of interrelated intrusion, metamorphism, and vein emplacement during which monzonite masses both truncated and were invaded by mineralized veins. Umpleby and Jones (1923) extended these studies, concluding that the ore deposits of the Coeur d'Alene district were formed in the late Mesozoic as hot, ascending solutions deposited metals derived from either underlying magmas or disseminated ores in the sedimentary wall rocks. They favored a magmatic source for these metals (Umpleby and Jones, 1923, p. 149). These early studies related the ore-bearing veins to Mesozoic igneous activity but debated sedimentary versus igneous sources for the metals. McDowell (1971) obtained K-Ar ages on hornblende from monzonite of the Gem stocks of 131-137 Ma (corrected to currently accepted decay constants), establishing a maximum age for at least some of the Coeur d'Alene veins. Schalck (1989) summarized age results for a northeast-trending group of plutons that includes the Gem stocks (Fig. 1), showing apparent ages ranging from about 100 Ma for the Trout Creek pluton in the northeast to 137 Ma at Gem. Age and isotopic studies by Fleck and Criss (1985) and Criss and Fleck (1987, 1990) established the Cretaceous and early Tertiary age of the northern (Bitterroot) lobe of the Idaho batholith and its related, regional-scale, metamorphic-hydrothermal system that includes the Coeur d'Alene district.

Kerr and Kulp (1952), Kerr and Robinson (1953), and Eckelmann and Kulp (1957) reported U-Pb ages ranging from 1190-1035 Ma for uraninite from pyrite-jasper veins in the Sunshine mine that predate base- and precious-metal veins. Long et al. (1960), Silverman et al. (1960), and Cannon et al. (1962) reported Pb-isotope data for galena from Coeur d'Alene veins that separated from parent uranium and thorium about 1400 Ma, concluding that these data established a Precambrian age of vein formation. Fryklund (1964) presented an alternative interpretation of the Pb-isotopic results, pointing out that a Precambrian age interpretation for Coeur d'Alene veins requires a pivotal assumption that the time of uranium separation was also the time of incorporation of Pb into the veins. Zartman and Stacey (1971) provided additional

Pb-isotopic results for galenas and endorsed the arguments for Precambrian mineralization. Hobbs (1971) reported a new U-Pb age of 1250 Ma on the uraninite veins, but expressed concern about the compatibility of this Middle Proterozoic U-Pb age with the timing of deformation of Belt strata in this area. From fluid inclusion and K-Ar studies, Leach et al. (1988) concluded that ore deposition occurred at 250° to 350° C at about 850 Ma, although the measured ages range from 876 Ma to 77 Ma. They considered apparent ages younger than about 850 Ma to be disturbed by subsequent thermal events. Leach et al. (1998a) reported new Ar-Ar apparent ages from sericite (muscovite in their Table 2) that range from 65 to over 1017 Ma. They argued that veins of the Coeur d'Alene district formed in both Proterozoic and Cretaceous time. A crucial study by Zartman and Smith (1995) demonstrated that uranium-bearing jasper veins of the Sunshine mine, dated originally at 800-1250 Ma, contained Early Cretaceous (133±6 Ma) zircons and brannerite. They concluded that these veins, which preceded the main-phase siderite-tetrahedrite veins, were emplaced in the Early Cretaceous, but incorporated variable amounts of Proterozoic common Pb and both detrital and volcanogenic(?) zircons.

Papers by Criss and Eaton (1998) and Leach et al. (1998b) define the present status of the controversy on the age of the Coeur d'Alene veins. The research on the age and origin of these veins over the last century has established a number of areas of agreement. Most investigators accept that Pb in the Coeur d'Alene veins separated from uranium in mid-Proterozoic time, probably about 1400±200 Ma. Where that Pb resided until the present is not an area of agreement, however (e.g. Fleck et al., 1991; Constantopoulos, 1994; Zartman and Smith, 1995; Leach et al, 1998a). Most current workers accept measurements of high $^{87}Sr/^{86}Sr$ in the carbonate gangue as evidence that those veins formed in Phanerozoic time. Although strong arguments can be made for this occurring in the late Mesozoic or early Tertiary (Criss and Fleck, 1990; Fleck et al., 1991; Eaton et al., 1995; Leach et al, 1998a), others have suggested that a pre-Belt source may have provided the highly radiogenic Sr to the veins in Proterozoic time (Rosenberg and Larson, 1996). Finally, there seems to be general acceptance that the primary vein materials were derived by metamorphic-hydrothermal processes from terranes whose protoliths were largely sedimentary (Leach et al., 1988; Criss and Fleck, 1990; Constantopoulos, 1994; Eaton et al, 1995; Leach et al, 1998a).

GEOLOGIC SETTING

The Coeur d'Alene mining district of northern Idaho and westernmost Montana (Fig. 1) lies within the Middle Proterozoic depositional basin of the Belt Supergroup, a thick sequence of marine, lacustrine, and terrestrial quartzite and argillite strata with several significant carbonate-rich intervals (Harrison, 1972). The district represents a west-northwest-trending zone of base- and precious-metal mineralization within the Lewis and Clark line, a 50- to 100-km-wide, 200- to 250-km-long zone of WNW-trending structures in northern Idaho and western Montana (Billingsley and Locke, 1939; Wallace, et al., 1960; Hobbs et al., 1965; Reynolds and Kleinkopf, 1977; Harrison et al., 1980; Price, 1981; White, 1998a, 2000; White and Applegate, 2000; White et al., 2000a). The mineralized area lies at the intersection of long-lived north-south-trending structures defined by Middle Proterozoic deposition as well as the more obvious north- to NNW-trending structures of the Cordilleran fold and thrust belt (Wallace, et al., 1960; Harrison et al., 1986; White, 2000). The Hope, Ninemile, St. Mary's, Osburn, and St. Joe faults represent significant vertical and horizontal displacements within the Lewis and Clark zone, but an abrupt transition from a northerly structural trend to a penetrative WNW tectonic fabric occurs near the Osburn fault (Wallace, et al., 1960; Hobbs et al., 1965; Harrison et al., 1980; Bennett and Venkatakrishnan, 1982; White, 1998a; White and Applegate, 2000). The Osburn fault, which bisects the Coeur d'Alene mining district along the same WNW trend, has about 26 km of right-lateral, strike-slip displacement (Hershey, 1916; Umpelby and Jones, 1923; Umpelby, 1924; Hobbs et al., 1965; Gott and Cathrall, 1980; Bennett and Venkatakrishnan, 1982). Strike-slip movement on the Osburn fault postdates much of the folding in the Coeur d'Alene district (Hobbs et al. 1965; White, 1998a), although we suggest that structural trends near the fault could have been modified by synchronous development of compressional features and strike-slip faulting, which is well documented along other major strike-slip structures such as the San

Andreas fault (Mount and Suppe, 1987; Miller, 1998). White (1998a) provides evidence that north-trending folds that define the primary structural trend north of the Coeur d'Alene district actually persist into the area near the Osburn fault where west-northwest-trending folds are predominant, although their effects are subtle. Both sets of folds appear to predate emplacement of the ore-bearing veins of the district, however. Deformation along the Lewis and Clark zone probably began in Precambrian time (White, 1994; 1998a; 2000). Displacement of 52±3 Ma-old, hornblende-bearing, granitic dikes by the Hope fault, one of the northernmost faults of the zone, however, indicates Eocene or younger movement (Fillipone et al., 1992). Numerous dikes in the Coeur d'Alene district occupy fractures subparallel to the Osburn fault. A K-Ar age of 52.0±1.5 Ma on biotite and similar but complex ages on hornblende are reported by McDowell (1971) for a lamprophyric dike in the Star mine, suggesting that other fractures within the Lewis and Clark line such as the Osburn fault also may have been active at this time.

Although exceptions occur, most economically important Pb-Zn-Ag veins of the district occur along northwest striking, south-southwest-dipping fractures, which are subparallel to high-angle faults, shear zones, fold axes, foliation, and axial-plane cleavage that define the dominant structural fabric on both sides of the Osburn fault (Fryklund, 1964). All of the vein systems predate movement along the Osburn fault and may be strongly sheared by post-emplacement movement along the fractures. Wavra et al. (1994) conclude that mineralization in the Sunshine mine occurred during a high-angle, reverse-slip, tectonic-metamorphic event, with major ore-shoots plunging steeply to the southwest. White (1998a) summarized observations supporting this interpretation. Vein systems in the district exhibit significant variability in mineralogy, but galena, tetrahedrite, and sphalerite are the most important ore minerals, whereas the primary gangue minerals are siderite, ankerite, and quartz in highly variable proportions (Fryklund, 1964).

ANALYTICAL METHODS

Rubidium-Strontium Methods

Whole-rock samples used in this study were crushed and split from 1 to 3 kg of rock, powdered to less than 200 mesh, and homogenized prior to taking aliquants for analysis. Carbonate mineral separates were made with heavy liquids, magnetic separation, and hand picking, with grain sizes ranging from 0.1 to 1.0 mm. Whole-rock samples were treated by standard silicate-digestion ($HF+HNO_3 \pm HClO_4$) techniques, whereas carbonates were digested in HCl. Following digestion of the samples, Rb and Sr were separated by ion-exchange techniques and concentrations were determined by isotope-dilution mass spectrometry. Two different techniques were utilized for carbonate samples. Early in the study HCl digestion was followed by precipitation of $Fe(OH)_2$ by addition of high-purity NH_4OH, filtration, and centrifugation. Siderites with 85-95% $FeCO_3$ required multiple cycles, during which co-precipitation of Sr resulted in reduced yields for mass spectrometry. Whereas the prior addition of ^{84}Sr tracer makes actual Sr yield of little consequence in most isotope dilution analyses, the precipitation procedure for removing $Fe(OH)_2$ is time consuming and probably results in co-precipitation of Sr. After the initial results made the value of the isotopic work clear, a second procedure was instituted involving no Fe precipitation. Samples were dissolved in HCl, dried, and redissolved in HNO_3. The solution was then passed through an Eichrom SrSpec column in 3M HNO_3. Sr was stripped with high-purity H_2O and analyzed directly on the mass spectrometer. Analyses are rapid and Sr yield is better than 95%. Analytical uncertainties in Rb and Sr concentrations are commonly 0.3 to 1.0 percent for concentrations above 25 ppm, but the coarse-grained siderites with 0.2 to 0.35 ppm Rb and 3 to 6 ppm Sr had variations of 3 to 5 percent, related in part to inhomogeneities in splitting. Isotopic measurements were made on a Finnigan MAT261 mass spectrometer with multiple collection. Analyses of National Bureau of Standards SRM 987 strontium carbonate (n=9) during processing of these samples averaged 0.710246±0.000011

(95% confidence). Constants used for Rb-Sr computations are: $\lambda_{Rb} = 1.42 \times 10^{-11}$ yr^{-1}, $^{86}Sr/^{88}Sr$ = 0.1194, and $^{85}Rb/^{87}Rb$ = 2.59265.

Stable Isotope Techniques

Siderite samples were reacted with 100% orthophosphoric acid (H_3PO_4) at 50°C to release CO_2 gas (Walters et al., 1972; Carothers et al., 1988). Detailed descriptions and a tabulation of stable isotope analyses are provided by Eaton (1993) and Eaton et al. (1995). Silicate rock samples were reacted with chlorine trifluoride (ClF_3) to release oxygen gas, which was then converted to CO_2 gas with a heated graphite rod (Clayton and Mayeda, 1963; Borthwick and Harmon, 1982). Samples were analyzed on a MAT 251 gas-source mass spectrometer with automated sample inlet system by standard techniques. The $\delta^{18}O$ values are reported relative to SMOW, whereas $\delta^{13}C$ values are relative to PDB.

RESULTS

Rb, Sr, $^{87}Sr/^{86}Sr$, $\delta^{18}O$ and $\delta^{13}C$ were measured on siderite, ankerite, and calcite mineral separates from base-and precious-metal-bearing veins of the Coeur d'Alene mining district (Table 1). Most of the analyses from the Sunshine mine were performed on the same mineral separates studied by Eaton (1993) and Eaton et al. (1995). Additional carbonate samples were collected at underground sites in the Coeur, Caladay, Galena, Gold Hunter, and Lucky Friday mines, and from mine dumps at the Matchless, Highland Surprise, Carbonate Hill, and Bullion mines (Fig. 1). These locations range approximately 45 km along the length of the district, from Pine Creek on the west (the Matchless mine) to the Bullion mine one mile west of the Montana State line. Two of the mines, the Lucky Friday and Gold Hunter, are north of the major WNW-trending Osburn fault, whereas the remaining eight are on the south side. Sampling within the Sunshine mine was the most extensive, covering nine major veins, depths from 500 to 5600 feet, and including two detailed sample traverses across the width of individual veins.

As may be noted in Table 1, Rb concentrations in the carbonate gangue from all the mines are extremely low, ranging from 0.03 ppm to less than 2 ppm. Sr concentrations in siderite are also very low, but values in calcite or ankerite may be greater than 1500 ppm, as in 918-17F calcite from the Highland Surprise mine. Measured $^{87}Sr/^{86}Sr$ ratios in the carbonate minerals are extremely high, averaging about 0.9, but with values greater than 1.6 (Table 1). All analyses lie above a 1600-Ma reference isochron on an Rb-Sr correlation diagram (Fig. 2), emphasizing the enormous enrichment of ^{87}Sr and the absence of any age-related correlation between $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ in the carbonate minerals. Plotting $^{87}Sr/^{86}Sr$ against 1/Sr, however, reveals an erratic but positive co-variation in the vein carbonates (Fig. 3). As might be expected from the wide variations measured within a given vein (Table 1), the vein-average data are dispersed, but reveal a clear trend (correlation coefficient $\cong 0.35$ for 1/Sr). Such a correlation would be expected from random mixtures of a high-Sr, low $^{87}Sr/^{86}Sr$ component with a second, containing low Sr and high but variable $^{87}Sr/^{86}Sr$. Variations of $^{87}Sr/^{86}Sr$ between samples are large even within individual veins (Table 2), but mean values of the vein systems reflect their geographic position. South of the Osburn fault, mines in the central or "Silver Belt" portion of the Coeur d'Alene district (the Sunshine, Coeur, Galena, and Caladay mines; Fig. 1) have significantly higher mean $^{87}Sr/^{86}Sr$ than those to the east or to the west. This central zone coincides roughly with the mineralized area where carbonate gangue is dominated by siderite, as noted by Fryklund (1964). Because Sr concentration increases with Ca concentration from siderite to ankerite to calcite (Tables 1, 2), the Sr content of vein carbonate (Table 1) also confirms the mineralogical variation of gangue within the district. The Sr content is higher in veins of the eastern and western parts of the district, where Fryklund reports ankerite instead of siderite.

Oxygen and carbon isotopic analyses have been described in detail elsewhere (Criss and Fleck, 1990; Fleck et al., 1991; Eaton et al., 1992; 1993; 1995) and will be discussed only as they relate to the interpretation of Sr results. Data reported in Table 1 are similar to those of Yates (1987) for the Galena mine (Fig. 1), defining a positive linear correlation between $\delta^{13}C$ and $\delta^{18}O$ (Fig. 4). The trends are similar to those defined in other carbonate-hosted, base- and precious-metal veins (Seal and Rye, 1992), as well as in metamorphic-hydrothermal systems (Nabelek et al., 1984), and are interpreted as primary hydrothermal variations established during ore deposition (Eaton et al., 1995).

Two of the sample suites in Table 1 represent sample traverses across siderite-tetrahedrite veins in the Sunshine mine at 10 cm intervals. The shorter crosses an uncomplicated part of the Copper vein (Fig. 5), whereas the longer traverse spans the width of a structurally complex part of the D-vein (Fig. 6). Stable isotope results for siderite from these traverses are crucial to interpretation of the timing of vein emplacement relative to regional metamorphism. Both vein traverses document significant variation in both Sr and stable isotope ratios. The quasi-symmetrical decrease in the heavy isotope (^{13}C and ^{18}O) from the vein margins to the center strongly supports a progressive growth of the veins inward from the walls of the fracture as fluid temperatures increased (Fig. 5). Based on these results, Eaton et al. (1995) argue that decarbonation of the fluids, caused by carbonate deposition, CO_2 loss, or both, may also have been a factor because temperature alone would be inadequate to reduce $\delta^{13}C$ to the extent observed. Whole-rock $\delta^{18}O$ values in the wall rock adjacent to the veins also increased (Fig. 6).

Large variations also occur in 1/Sr and $^{87}Sr/^{86}Sr$ across the veins. These two parameters are strongly correlated in Copper vein siderites (Fig.5), supporting arguments for a mixing relationship between components with high Sr, low $^{87}Sr/^{86}Sr$ and low Sr, high $^{87}Sr/^{86}Sr$. Because variations in $^{87}Sr/^{86}Sr$ are unrelated to isotopic fractionation, the correlation indicates a source-related control of Sr variation. Argillite in the Belt Supergroup is commonly higher in Rb/Sr and lower in Sr than quartzite- or limestone-dominated sequences. $^{87}Sr/^{86}Sr$ from old, high-Rb/Sr argillite will be much higher than Belt limestone or dolomite, which has minimal Rb and $^{87}Sr/^{86}Sr$ will be changed little from seawater values by ^{87}Rb decay (*e.g.*, Obradovich and Peterman, 1968). Quartzite of the Belt Supergroup commonly has lower Rb/Sr ratios than Belt argillite, and also may contain considerable carbonate. As a result, metamorphic fluids in equilibrium with Belt carbonate or quartzite would have lower $^{87}Sr/^{86}Sr$ than those from argillite of a similar age. Although less apparent in Copper vein analyses (Fig. 5), analyses of the D-vein record a clear but imperfect anti-correlation between Sr and stable isotopes variations (Fig. 6).

Regardless whether these variations are source-controlled or fractionation-related, the large, systematic isotopic variations documented across Coeur d'Alene veins are related to primary fluctuations in the ore-forming fluids that were established during vein deposition and argue against post-depositional metamorphic homogenization.

SOURCE OF STRONTIUM IN COEUR D'ALENE CARBONATE VEINS

As illustrated in an isochron diagram (Fig. 2), the extremely radiogenic $^{87}Sr/^{86}Sr$ in Coeur d'Alene carbonate gangue minerals with very low $^{87}Rb/^{86}Sr$ could not have evolved in situ. Decay of present amounts of Rb in these minerals would account for only trivial amounts of the radiogenic ^{87}Sr. The Sr in carbonate vein minerals is so highly radiogenic that if we assume an initial $^{87}Sr/^{86}Sr$ (Sr_i) equal to modern seawater (0.70915), the *youngest* Rb-Sr apparent age of all these carbonate minerals (7.44 Ga) would exceed the age of Earth. The unsupported radiogenic ^{87}Sr and high $^{87}Sr/^{86}Sr$ of the veins are incontrovertible evidence that the Sr evolved in a system with substantially higher Rb/Sr over a significant period *prior* to incorporation in the vein. An ancient, high Rb/Sr source must have been available at the time of vein formation or the highly radiogenic $^{87}Sr/^{86}Sr$ must have been introduced long after the veins were formed. Clearly, neither the most profoundly enriched mantle nor ancient lower crust is a potential source of the radiogenic Sr. The most obvious source of highly radiogenic $^{87}Sr/^{86}Sr$ is the variably metamorphosed, high-Rb/Sr sedimentary rocks of the Belt Supergroup (Hobbs et al., 1965; Harrison, 1972; Gott and Cathrall, 1980; Hietanen, 1962; 1967; 1984; Criss and Fleck, 1987; 1990). Not coincidentally, the Belt rocks have long been viewed as the source of the ore metals (e.g. Hershey, 1912; 1916) and, more recently, the source of high $\delta^{18}O$ in Coeur d'Alene veins (Criss and Fleck, 1990; Constantopoulos and Larson, 1991). An alternative explanation for the high $^{87}Sr/^{86}Sr$ might be to derive it from a high-Rb/Sr, pre-Belt basement that is not exposed in the district. Growth of the high $^{87}Sr/^{86}Sr$ could have occurred in Archean time, permitting a Proterozoic age for the veins. A different explanation that must be considered is that the elevated $^{87}Sr/^{86}Sr$ was introduced metasomatically into veins of Precambrian age during

Mesozoic or early Tertiary metamorphism. Each of these explanations for the high $^{87}Sr/^{86}Sr$ observed in Coeur d'Alene ore veins affects the age assigned to that mineralization, making this evaluation critical to attaching age significance to these results.

Belt Supergroup

Evidence pointing to the Belt rocks as the probable source of Sr in Coeur d'Alene ore veins is compelling. As discussed, Sr isotopic compositions of the carbonate gangue preclude any possibility of significant *in situ* growth from decay of ^{87}Rb. In addition to their mineralogy, the dominantly-carbonate ore veins exhibit abundant evidence of fluid (hydrothermal) origin, as discussed by numerous workers (Lindgren, 1904; Hobbs et al., 1965; Leach et al., 1988; Criss and Fleck, 1990; Constantopoulos and Larson, 1991; Eaton, 1995). Highly radiogenic Sr must have been incorporated into the carbonate veins without supporting Rb, but the time of incorporation must be determined to constrain the age of the veins. If the isotopic character of the veins can be shown to be primary, formed during initial deposition from metamorphic hydrothermal fluids, Sr with highly radiogenic $^{87}Sr/^{86}Sr$ must have been incorporated from an old, high Rb/Sr source and deposited with the ores from the vein-forming liquids. The veins must be younger than that source by the amount of time required for its very large $^{87}Sr/^{86}Sr$ to be produced by decay of ^{87}Rb. If the highly radiogenic Sr was leached from Belt strata, the time required for growth of ^{87}Sr in those rocks can be estimated from Table 3, using the median $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ of Belt Supergroup rocks and their initial $^{87}Sr/^{86}Sr$. Based on these results, Belt wall rocks would have required at least 1000 m.y. to reach the median $^{87}Sr/^{86}Sr$ (0.906) of Coeur d'Alene veins. Because $^{87}Sr/^{86}Sr$ ratios as high as 1.6 are measured in the veins (Table 1), only Belt strata with the highest Rb/Sr could have been a source for this Sr (Fig. 7). Even with the age of the Belt Supergroup in the Coeur d'Alene district as old as 1440 Ma (Aleinikoff et al., 1996), the $^{87}Sr/^{86}Sr$ in the strata would not have been sufficient to be a source for the veins until Mesozoic time. These relationships, illustrated in Figure 8 at 850 Ma, show that in Late Proterozoic time $^{87}Sr/^{86}Sr$ values of Belt strata would not have been high enough to produce veins with $^{87}Sr/^{86}Sr$ over 1.0. Formation of these veins in Proterozoic time is precluded.

The genetic model of deriving highly radiogenic Sr from rocks of the Belt Supergroup involves depositing the carbonate-rich ore veins of the Coeur d'Alene district from Cretaceous or early Tertiary metamorphic-hydrothermal fluids. The presence of a metamorphic-hydrothermal system throughout much of northern Idaho at this time is well documented (Criss et al., 1984; Criss and Fleck, 1987, 1989a,b, 1990; Fleck and Criss, 1985; Constantopoulos, 1994). This model holds that Sr, as well as most other components of the veins (the carbonate, the base- and precious-metals, and the Fe, Mn, and Ca), were leached by the fluids from the Belt wall rocks prior to and during emplacement of the veins. The Sr, the Fe-rich carbonate, and the ore minerals were subsequently deposited from these fluids in veins that grew progressively, probably from their margins to their centers. The high-^{18}O fluids clearly underwent extensive exchange with the metasedimentary rocks of the Belt Supergroup, and most likely represent ordinary metamorphic or formation fluids with little or no contribution from magmatic sources. This absence of a significant igneous component in the fluids is consistent with Pb isotope results for Coeur d'Alene ores (Zartman and Stacey, 1971) and makes magmatic fluids, such as from the Gem stocks, improbable sources for the metals.

Unexposed Archean Basement

Rosenberg and Larson (1996) suggest that veins of the Coeur d'Alene district may have been derived from "older pre-Belt rocks that were already ^{87}Sr-rich a billion years ago". To satisfy this model, a source terrane older than 2500 Ma would need to have Rb/Sr values approaching the high values of the Belt Supergroup. Results of Sr studies of Precambrian crystalline rocks west of the Purcell Trench (Armstrong et al., 1987) and Archean rocks east of the Belt basin (James and Hedge, 1980; Henry et al., 1982; Wooden and Mueller, 1988; Mock et al., 1988; Mueller et al., 1993) provide a comparison of $^{87}Sr/^{86}Sr$ and Rb/Sr in pre-Belt basement to those observed in Belt strata (Table 4). Calculated for a growth over 850 m.y. (Fig. 9),

$^{87}Sr/^{86}Sr$ values of these Archean or Early Proterozoic rocks would have been far below the range of values found in Coeur d'Alene veins. Although the Archean rocks are 1000 to 1500 m.y. older than the Belt rocks, their present-day $^{87}Sr/^{86}Sr$ values do not approach those of present Belt strata. Consequently, those rocks could not have been the source of high $^{87}Sr/^{86}Sr$ *today*, let alone 800 to 1000 m.y ago (Fig. 9). Considering the range of $^{87}Sr/^{86}Sr$ in Archean rocks exposed in the region, arguments suggesting an Archean basement source for the vein Sr are not supported. Measured values of $^{87}Sr/^{86}Sr$ consistently above 1.0 are only obtained from high-Rb/Sr, sedimentary or metasedimentary units in which ^{87}Rb has decayed for 1000 m.y. or more prior to Sr mobilization. The high $\delta^{18}O$ values of the veins clearly reflect fluids equilibrated with metasedimentary sources (Criss and Fleck, 1987, 1990; Constantopoulos and Larson, 1991; Eaton et al., 1995). Clearly, the carbonate that represents 50-95 percent of the gangue in many Coeur d'Alene vein systems was derived from an originally sedimentary source. In the Coeur d'Alene region, only rocks of the Belt Supergroup meet these criteria as the source for the carbonate vein systems (Fleck and Criss, 1985; Criss and Fleck, 1987).

Further evidence for the type of crust beneath the Coeur d'Alene district is provided by Sr measurements of the Gem stocks (Table 5). As shown in numerous studies (e.g., Kistler and Peterman, 1973; Armstrong et al., 1977; Fleck and Criss, 1985), initial $^{87}Sr/^{86}Sr$ ratios of plutons commonly represent the average isotopic composition of their sources. Initial $^{87}Sr/^{86}Sr$ ratios of the Gem stocks are about 0.7053, whereas most Mesozoic or younger plutons intruding Proterozoic or older crust commonly have ratios >0.706 (Kistler and Peterman, 1973; Armstrong et al., 1977, 1987; Farmer and DePaolo, 1983, 1984; Fleck and Criss, 1985). The only other plutons emplaced through Precambrian crust in this region with such anomalously low $^{87}Sr/^{86}Sr$ values are Eocene quartz monzonite and granite bodies that extends westward from Lake Pend Oreille (Idaho) into northeastern Washington (Table 5). These are described by Whitehouse et al. (1992), who interpret Nd and U-Pb results as indicating a depleted, Late Archean or Early Proterozoic, lower-crustal source. Like their Sr initial ratios, feldspar Pb-isotope ratios of these plutons are anomalously low and strikingly similar to those of Coeur d'Alene galenas (Zartman and Stacey, 1971). These values suggest similarities in crustal sources for the Eocene plutons and the Gem stocks that are distinct from those of the Wyoming craton or the Spokane dome (Farmer and DePaolo, 1983, 1984; Armstrong et al., 1987; Wooden and Mueller, 1988; Mueller et al., 1988; Wooden et al., 1988; Whitehouse et al, 1992). None of these results suggests that any Archean rocks present as basement to the Belt Supergroup in the Coeur d'Alene district have $^{87}Sr/^{86}Sr$ values sufficiently high to be the source for the Sr in the Coeur d'Alene veins in Proterozoic or even Tertiary time.

The presence of a substantial Archean crust beneath the Coeur d'Alene district is also questioned by Nd and U-Pb studies of the northeastern Idaho batholith, which intrudes rocks of the Belt Supergroup in the southern part of the Belt basin. Mueller et al. (1995) report Nd model ages of 1720 to 2170 Ma for these plutons, suggesting an Early Proterozoic crustal residence for the source. Although the presence of a subordinate Archean component cannot be eliminated, it is largely masked by Early Proterozoic elements. U-Pb studies of single zircons from these plutons using the SHRIMP ion microprobe also indicate dominance of an Early Proterozoic source of the magmas. An upper intercept U-Pb age of 1743 ± 43 Ma was calculated from these analyses, which appeared to represents a single, coherent population. Mueller et al. (1995) interpret these results as closely representing the age of the predominant source of the magmas in the region. Foster and Fanning (1997) obtained similar SHRIMP results from plutons in this area, concluding that the age of the primary source of plutons of this region was about 1750 Ma. These results make the presence of any substantial Archean source under the Coeur d'Alene district and at least the southern part of the Belt basin improbable.

Metasomatic Exchange of Sr in Carbonate Veins

Unequivocal evidence for metasomatic mobilization of Sr in the Coeur d'Alene district in the Mesozoic or later is found both in carbonate veins and wall rocks of the Belt Supergroup. The enormous scale of the metamorphic-hydrothermal system associated with the Idaho batholith in Cretaceous and early Tertiary time is well documented (Criss et al., 1984; Fleck and

Criss, 1985; Criss and Fleck, 1987, 1989a,b, 1990). The process operated from the scale of intergranular exchange to large-scale fracture flow. First, as documented here, measured $^{87}Sr/^{86}Sr$ ratios of low-Rb carbonate veins are as high as 1.6, similar to the highest values measured in high-Rb, low-Sr argillite of the Belt Supergroup (Table 3). Second, Rb-Sr studies document the redistribution of radiogenic ^{87}Sr in Belt strata (Obradovich and Peterman, 1968; Fleck and Criss, 1985; Criss and Fleck, 1987; 1990). Model ages of high-Rb/Sr argillites are substantially lower than the presumed1400-1500 Ma age of the strata, whereas those of low Rb/Sr quartzites or limestones may be much older (Table 3). Errorchrons for Belt clastic rocks flatten at high Rb/Sr, but even lower Rb/Sr data may define apparent ages less than the presumed age.

Finally, analysis of a 500-g limestone nodule contained in high-Rb/Sr shale of the Wallace Formation near Osburn (Fig. 1) confirms the increase in $^{87}Sr/^{86}Sr$ in low-Rb/Sr Belt carbonate rock (sample 918-13C, Table 3) during metamorphism. Because the small-volume nodule was completely enclosed in high-Rb, low-Sr shale during the hydrothermal event, metasomatic effects were expected, but the limestone exhibits no significant textural or fabric evidence of metasomatism. Analyses reveal, however, a measured $^{87}Sr/^{86}Sr$ of 0.768 for this sample, compared to a value for Proterozoic seawater of less than 0.710 (e.g., Obradovich and Peterman, 1968;Veizer et al., 1983; Veizer, 1989; Mirota and Veizer, 1994). The low Rb/Sr ratio of this limestone of 0.055 yields a model age in excess of 10 Ga and clearly documents the presence of fluid-derived ^{87}Sr. The enclosing shale of the Wallace Formation (sample 918-13D) yields a measured $^{87}Sr/^{86}Sr$ of 0.91182, an $^{87}Rb/^{86}Sr$ of 14.9, and an apparent age of about 850 Ma. The absence of Sr isotopic equilibrium between the limestone and surrounding shale documents the open-system behavior of the rocks expected in metasomatism.

Considering the evidence of substantial metasomatism of Belt strata, is it possible that carbonate veins formed in Proterozoic time obtained their high $^{87}Sr/^{86}Sr$ ratios during Mesozoic metasomatism? Although ample evidence of Sr mobility exists, metasomatism of pre-Mesozoic veins by high $^{87}Sr/^{86}Sr$ fluids *cannot* explain the enormous $^{87}Sr/^{86}Sr$ ratios of Coeur d'Alene veins. Several lines of evidence preclude this origin for the majority of the ore veins. First, the $^{87}Sr/^{86}Sr$ of the veins ranges from 0.74 to 1.64 with a mean for all sampled veins over 1.00 and a median of 0.96. Metasomatism increased the $^{87}Sr/^{86}Sr$ in the limestone nodule (Table 3) to 0.768, but even this special circumstance did not produce values approaching 0.8.

Secondly, stable isotope co-variations within the veins reflect primary hydrothermal characteristics, not the homogenizing effects of metasomatism. The quasi-linear covariation of $\delta^{18}O$ and $\delta^{13}C$ that characterizes hydrothermal deposits is not overprinted by metasomatic homogenization. Increased wall rock $\delta^{18}O$ adjacent to the high-$\delta^{18}O$ veins also argues against post-depositional metamorphism of these veins, pointing instead to advection of hotter, deeper fluids producing conditions of isotopic disequilibrium (Eaton et al., 1995). Harris et al. (1981) found that $\delta^{34}S$ also exhibits primary hydrothermal variations in the Sunshine mine, including at least local variation with depth.

Most importantly, detailed sampling profiles across Coeur d'Alene ore veins (Eaton et al., 1995) have demonstrated an enormous, isotopically correlated, centimeter-scale variation in $\delta^{18}O$, $\delta^{13}C$, Sr, and $^{87}Sr/^{86}Sr$ (Fig. 5,6). These correlated isotopic variations are conclusive evidence that the veins exhibit primary hydrothermal character that has not been homogenized by metamorphism. These veins record progressive, time-dependent, incremental growth patterns and abrupt changes in their chemical and isotopic composition, representing changes in the character of the fluids during deposition. Regional metamorphism involving large-scale, metasomatic introduction of Sr (and other components) into these veins *subsequent to deposition* almost certainly would have caused homogenization of the primary isotopic variations of both radiogenic and stable isotopic systems. If the veins had formed in the Proterozoic and the high $^{87}Sr/^{86}Sr$ ratios established during Mesozoic and Tertiary metasomatism, those isotopic ratios would have been much more uniform across the veins. Although leaching of wall rocks, exchange with solid phases, and some homogenization clearly occurred at an intergranular scale during the Mesozoic or younger metamorphic-hydrothermal event, primary deposition of Sr-bearing ore veins in through-going fracture systems is required by the results.

Interpretation of Sr Results

Strontium, oxygen, and carbon isotopic ratios provide strong constraints on the age, source, and mode of origin of most of the Coeur d'Alene veins. Highly radiogenic Sr, metasedimentary stable-isotope signatures, and most of the metals deposited in the ore veins were derived from sources within the Belt Supergroup during a metamorphic-hydrothermal episode in Mesozoic or younger time. Carbonate-rich ore veins were deposited from thermally driven fluids that scavenged these components from the Belt strata. Evidence for the metamorphic-hydrothermal system that existed throughout much of northern Idaho in late Mesozoic and early Tertiary time and was probably responsible for Coeur d'Alene vein mineralization was discussed earlier (Criss et al., 1984; Fleck and Criss, 1985; Criss and Fleck, 1987, 1989a,b, 1990; Leach et al., 1988; Constantopoulos, 1994).

Leach et al. (1998a) argue that many Pb-Zn veins of the Coeur d'Alene district formed in the Proterozoic, but do not exclude possible mobilization of strata-bound deposits during the Mesozoic. In veins where the $^{87}Sr/^{86}Sr$ ratios of the carbonate phases are less than about 0.78, that possibility cannot be discounted. To be so, however, one must accept either that the folds and faults occupied by *both* Proterozoic and Mesozoic/Early Tertiary veins formed in the Proterozoic or that the old structures and their veins were not folded or otherwise deformed seriously during any subsequent deformation. We consider both possibilities unlikely. Abundant evidence of intense Mesozoic-Cenozoic deformation, metamorphism, intrusion, and hydrothermal activity contrasted with indications of gentle folding and tilting in the Proterozoic (Harrison, 1986) suggests that most of the vein-controlling structures and both types of veins formed in Mesozoic or younger time. Based on evidence cited and interpretations presented by Wells (1974), White (1998a), and White et al. (2000b), a Mesozoic age for the folding and thrust faulting appears most likely. Only 30 miles to the east of the Coeur d'Alene district in Montana apparently synchronous thrust faults and folds with styles and trends typical of the district deform the disconformable but concordant contacts between Cambrian rocks and Proterozoic

Belt strata. In our view this evidence precludes a Proterozoic age for any significant folding or thrust faulting and is consistent with a Mesozoic or younger age for the major folds, faults, and ore-bearing veins contained within them in the Coeur d'Alene mining district (White, 1998a).

INTERPRETATION OF Pb AND Ar RESULTS

As discussed earlier, conflicting results from U-Pb, K-Ar, and Ar-Ar studies of Coeur d'Alene veins permit the interpretation that some of the veins were emplaced in Proterozoic time (Kerr and Kulp, 1952; Kerr and Robinson, 1953; Eckelmann and Kulp, 1957; Long et al., 1960; Silverman et al., 1960; Cannon et al., 1962; Zartman and Stacey, 1971; Leach et al. 1988; 1998a,b; Zartman and Smith, 1995). Without the strong structural evidence to the contrary, the model of Proterozoic and Mesozoic vein-forming episodes suggested by Leach et al. (1998a,b) cannot be discounted completely despite irrefutable Sr isotope evidence that most vein systems in the Coeur d'Alene mining district are Mesozoic or younger. Because geologic evidence constrains the structures occupied by the vein systems to be Paleozoic or younger (White, 1998a; White et al., 2000b), however, lead and argon isotopic results indicating a Proterozoic age require explanation.

Pb Isotope Studies

Isotopic evidence indicates that most of the Pb in veins of the Coeur d'Alene district was separated from U between 1500 and 1200 Ma, at or near the time of Belt sedimentation (Long et al., 1960; Cannon et al., 1962; Zartman and Stacey, 1971; Aleinikoff et al., 1996). This so-called "Coeur d'Alene-type" Pb was most likely separated from uranium during or shortly after the 1400- to 1500-Ma deposition of Belt strata. The model most consistent with isotopic results is that Pb and other base metals were deposited with the earliest Belt sediments as syngenetic, sediment-hosted, massive sulfide deposits. Following suggestions by Zartman and Stacey (1971), Leach et al. (1998a) also conclude that stratiform lead-zinc deposits were formed during Belt sedimentation, but they propose that Coeur d'Alene veins formed at about 1000 Ma.

Although stratiform mineralization has been described at the Bunker Hill and Lucky Friday mines (Vulimiri and Cheney, 1981; Ramalingaswamy and Cheney, 1982; White, 1998b), these deposits are probably not syngenetic, but controlled by sedimentary structures, susceptibility to cataclasis, permeability, and proximity to major vein systems (Reid, 1982; White, 1998b). Although not identified in the district, syngenetic, sediment-hosted, massive sulfide deposits, such as occur within Belt-equivalent strata at Sullivan, British Columbia (e.g., Beaudoin, 1997), are the most likely sources of Pb in the Coeur d'Alene district because of the synchronism of sedimentation and isolation of significant amounts of Pb from uranium. Neither U-Pb or Pb isotopic evidence indicates vein formation in the Coeur d'Alene district at 1000 Ma.

During formation of the Coeur d'Alene veins, hydrothermal fluids almost certainly scavenged Sr and Pb from both radiometrically evolved Belt strata and radiometrically retarded stratiform deposits or marine limestones. Clearly, the Pb budget in ore-fluids derived from syngenetic deposits containing Belt-age galena with nearly 87 percent Pb by weight will be dominated by isotopically retarded Proterozoic Pb. Zartman and Stacey (1971) argue that mobilizing stratiform Pb into veins close to its age of deposition would result in much less contamination of the veins by radiogenic Pb from the Belt strata than after 1400 to 1000 m.y. Although valid, the amount of Pb formed in Belt strata by the decay of less than about 6 ppm uranium at virtually any age will show little effect on Pb from stratiform galena. Pb with an isotopic composition established in the Proterozoic only establishes a *maximum* age for mineralization, unless related genetically to vein formation. "Coeur d'Alene-type" Pb could have been mobilized from a Proterozoic massive-sulfide source at any time from approximately 1450 Ma to the present, based on the age of the Belt Supergroup.

Zartman and Stacey (1971) report many Pb-bearing ore deposits emplaced in Belt strata throughout northwestern Montana and northern Idaho that were undoubtedly deposited in Mesozoic or Cenozoic time, based on their much more radiogenic Pb-isotope compositions. These deposits are scattered geographically and interspersed with deposits characterized by Proterozoic Pb (Zartman and Stacey, Fig. 2, 1971). Deposits dominated by Proterozoic Pb, however, appear to be strongly localized by a north-trending lineament, called the Noxon line or arch by White and Applegate (2000). White and Applegate (2000) argue that faulting along the Noxon line controlled the deposition of syngenetic Pb-Zn-Ag ore bodies from the Sullivan mine in British Columbia south to the Coeur d'Alene district, where the arch intersects the Lewis and Clark line. This intersection was represented as a "structural knot" by Wallace et al. (1960), who also note that the Gem stocks were emplaced into this structure. Mesozoic and early Tertiary magmatism and tectonism subsequently produced a geographic intermingling of ore deposits in the region, forming ore bodies with significant radiogenic Pb away from the Noxon arch and ones dominated by remobilized, Coeur d'Alene-type, retarded Pb along the arch where it was deposited originally in the Proterozoic (Zartman and Stacey, 1971; White and Applegate, 2000).

Until recently, Proterozoic ages assigned to Coeur d'Alene veins were based primarily on 1000-1200 Ma ages obtained for uranium-bearing jasper veins in the Sunshine mine (Kerr and Kulp, 1952; Kerr and Robinson, 1953; Eckelmann and Kulp, 1957; Silverman et al., 1960; Long et al., 1960; Leach et al., 1988, 1998a,b). Zartman and Smith (1995) eliminated this constraint with their study of uranium-bearing veins of the Sunshine mine, establishing the age of the U-bearing mineral, brannerite, and that of co-existing zircon and pyrite as 133±6 Ma. These results not only remove any requirement of a Proterozoic age, but constrain the age of the younger, siderite-tetrahedrite veins of the Sunshine Mine to Cretaceous or younger, in so far as they crosscut the uranium-bearing veins (Kerr and Robinson, 1953).

Leach et al. (1998a,b) report Pb isotope ratios for siderite and tetrahedrite from the Sunshine, Galena, and Hypotheek mines that are much more radiogenic than galena from the same vein systems. Adding measurements of highly radiogenic Sr in Sunshine and Galena mine siderites (Table 1) to the Pb results of Leach et al. (1998a,b) and Cannon et al (1962) extends this paradox by analogy to the Gold Hunter, Lucky Friday, and Highland Surprise mines. The Pb isotopic compositions of galena and tetrahedrite from these vein systems preclude their simultaneous deposition from the same fluids. This apparent isotopic disequilibrium must be explained by either spatially, mechanically, or temporally separate emplacement of these ores.

Leach et al. (1998a,b) emphasize a bimodal character of Coeur d'Alene veins, concluding that Pb-Zn veins formed in the Proterozoic, whereas Ag-rich, siderite-tetrahedrite veins were deposited in Mesozoic/Cenozoic time. This interpretation would require that the vein systems in at least these six mines include veins formed almost 1000 m.y. apart, occupying the same, almost certainly Paleozoic or younger, geologic structures (White, 1998a). Conversely, abundant evidence cited above suggests that most of the structures and both types of veins formed in Mesozoic or younger time. Hobbs et al (1965) demonstrated this conclusively for the Puritan fault (Fig. 1), for which substantial displacement juxtaposes unmetamorphosed Prichard against monzonite of the North Gem stock. The Puritan fault localized concentrations of ore sufficient for mining over a vertical distance of 1000 feet in the Tamarack mine, yet fault movement subsequent to ore emplacement was considered minor by Hobbs et al. (1965).

Although the Pb isotopic differences indicate that most Pb-Zn and siderite-tetrahedrite mineralization was derived from different sources, they do not constrain the timing of vein formation. Although Pb with "Coeur d'Alene-type" isotopic ratios indicates an originally Proterozoic source, evidence suggests that galena in Coeur d'Alene veins was almost always introduced late in the paragenetic sequence (e.g. Hershey, 1916; Fryklund, 1964). As would be expected from the absence of Proterozoic Pb contamination found in the tetrahedrite by Leach et al. (1998a), galena following siderite-tetrahedrite is the most commonly observed paragenetic sequence where both mineral associations occur (Fryklund, 1964; Brian White, written comm., 2000). Analyses of siderite from sample profiles across siderite-tetrahedrite veins reveal extreme variations in $^{87}Sr/^{86}Sr$, demonstrating that layers were deposited sequentially. Extending these observations to the paragenetic sequences of the veins, suggests that not only were different metallic mineral species deposited at different times, but that metal such as Pb from different sources was also deposited sequentially. This would be especially true if the Coeur d'Alene-type Pb were derived from syngenetic sediment-hosted massive sulfides that were low in Ag and Cu, favoring galena over tetrahedrite deposition. We suggest that the vein systems of the Coeur d'Alene district formed in Mesozoic or younger time in multiple ore-forming pulses involving fluids derived from or passing through different sources within the Belt Supergroup with extremely different Sr and Pb isotopic compositions. At least one of these sources probably included syngenetic, stratiform Pb-Zn deposits.

Argon Geochronology in the Coeur d'Alene District

K-Ar and Ar-Ar apparent ages of muscovite and phlogopite from veins of the Coeur d'Alene mining district range from 1018 Ma to <74 Ma with a spectrum of intermediate values that is far from bimodal (Leach et al., 1988, 1998a; Rosenberg and Larson, 1996). Leach et al., (1998a) present data for an even-younger muscovite from altered wall rock adjacent to a vein outside the district (ca. 64 Ma, Baychief mine). In this latter case, wall-rock muscovite has clearly been reset from an earlier detrital, diagenetic, or burial-metamorphic age, but what is the origin of muscovite found in Coeur d'Alene veins? Leach et al. (1998a) report a disturbed Ar-Ar age spectrum for muscovite from the Lucky Friday mine they interpret as reflecting argon loss and a minimum age of 1018 Ma. They interpret this as evidence of a Proterozoic vein-forming event at about 1000 Ma, during which muscovite (sericite) formed in the vein. Paradoxically, Lucky Friday veins also yield siderite with $^{87}Sr/^{86}Sr$ of 0.833-0.857 (Table 1). Belt strata with a median $^{87}Rb/^{86}Sr$ (Table 3) would require about 750 m.y. to generate an $^{87}Sr/^{86}Sr$ of 0.833-0.857. With an age of 1440 Ma for the Belt strata, this could not be achieved until 690 Ma, long after the apparent age of the muscovite. The physical relationship between the muscovite and the siderite samples is not known, but the minimum age indicated for the mica is not consistent with its primary crystallization from the siderite-bearing veins.

A possible explanation of this paradox is that muscovite-bearing wall rock adjacent to major veins such as the Lucky Friday vein has been incorporated into the mineralized zones as ore fluids spread outward from the primary vein systems and vein minerals were deposited within the sheared wall rock. Reid (1982) reports petrographic study of this process for the Bunker Hill mine, where 10 percent of the rock was sericite and galena was about 5 percent. Fryklund (1964) found that muscovite was present in the veins as both "a constituent of unreplaced country rock and as recrystallized material". The mica may have formed within Belt strata during Proterozoic burial metamorphism, perhaps during periods of elevated thermal gradient that may have accompanied orogenic events recognized in British Columbia (McMechan and Price, 1982; Anderson and Davis, 1995; Doughty et al., 1998). Alternatively, the muscovite could have been formed in bedding-parallel veins during burial metamorphism of the pelitic sediments, folded and faulted prior to mineralization, and incorporated into Coeur d'Alene mineralization in the same passive way as any of the incompletely replaced country rock.

The Ar-Ar age spectrum of muscovite from the Lucky Friday vein reported by Leach et al. (1998a) is consistent with Mesozoic or younger Ar loss due to temperatures that exceeded its Ar closure-temperature, which averages about 325°C (Snee et al., 1988; Hames and Hodges, 1993). This Ar loss could have occurred when muscovite in "unreplaced country-rock" adjacent to the Lucky Friday vein was saturated by the mineralizing fluids and incorporated into the ore. Leach et al. (1988) subdivide fluid-inclusions in Coeur d'Alene veins into three types, based on the phase state and chemical composition of their fluids. They found that homogenization temperatures of their Type 1 inclusions, including some from the Lucky Friday mine, were in the range of 225° to 300°C. They suggest that actual trapping temperatures may be as much as 50-100°C higher at 0.1Gpa (1 kbar) pressure. Hames and Hodges (1993) calculate minimum and maximum Ar closure temperatures for 1mm muscovite grains of 253° and 392°C, respectively, suggesting significant Ar loss could have occurred near crystal rims. Cores of grains may have suffered minimal Ar loss, however, as the grains were neither recrystallized or replaced. Clearly, temperatures in the veins could have been either above or below the approximate closure-temperature for Ar in muscovite. Soaked with hydrothermal fluids at temperatures of 225° to 400°C, muscovite could lose large or small amounts of its pre-existing radiogenic Ar, depending on the temperature of the fluid and its rate of cooling. Temperatures would be lower and cooling would be faster with increasing distance into the wall rock from the primary vein.

Whole-rock K-Ar apparent ages of muscovite- or sericite-dominated Belt metasedimentary rocks range from 45 Ma near the Idaho batholith to values of 1033 Ma near Avery, Idaho (Armstrong, 1976). The rocks near Avery not only yield apparent ages as high as 1033 Ma, but values as low as 189 Ma are measured only a few miles away (Armstrong, 1976). An age of 530 Ma at the Silver Summit mine in the Coeur d'Alene district is reported by Armstrong (1976). This pattern of variable apparent ages is typical of metamorphic terranes and nearly identical to that of muscovites from Coeur d'Alene veins, as shown in Figure 1 of Leach et al. (1998b). This distribution is characteristic of Ar loss from the rocks subjected to temperatures near or slightly above their Ar closure-temperatures or where temperatures vary over short distances due to the distribution of more local heat sources, such as veins or dikes.

Vein muscovites from the Sunshine mine that yield a K-Ar apparent age of 77±5-Ma (Leach et al., 1988) and a gently sloping, Ar-Ar age spectrum with an 85-Ma total-gas age (Leach et al., 1998a) indicate a Late Cretaceous or younger cooling of these veins. Whether these results represent nearly complete resetting of incorporated muscovite or primary growth of muscovite in the vein followed by mild reheating is not established, but the continuum of disturbed ages from 1018 Ma to 64 Ma favors the former. Although temperatures of the siderite veins in the Coeur d'Alene district may have exceeded 325° to 350°C locally, temperatures in local Belt rocks outside the veins commonly did not reach these temperatures. Metamorphic temperatures in the most deeply buried strata may have reached those of the biotite zone, but sericitic alteration of clays is generally the limit of local metamorphism (Hobbs et al., 1965). Although their mode of origin may be ambiguous, the Cretaceous apparent ages of some of these micas confirm Mesozoic or younger vein formation in the district. In our view, however, the significance of the Proterozoic Ar-Ar ages of vein muscovites remains uncertain.

CONCLUSIONS

Results of Sr isotopic studies of carbonate-dominant veins and associated Pb and Ag ores of the Coeur d'Alene mining district indicate that the majority of these veins were deposited in

Cretaceous or early Tertiary time, consistent with structural evidence requiring a Paleozoic or younger age for unfolded veins. Ore-forming fluids were driven by metamorphic-hydrothermal system associated with Cretaceous or Early Tertiary deformation and plutonism that included the Idaho and Kaniksu batholiths and their precursors (Criss and Fleck, 1990). These fluids scavenged metals from Proterozoic concentrations in the strata of the Belt Supergroup that may include undiscovered Sullivan-type syngenetic Pb-Zn deposits. Monzonite intrusive rocks of the Gem stocks probably represent minor perturbations of the thermal regime and are largely unrelated to the ore bodies. The ore-forming fluids were not derived from the Gem stocks and only minor igneous contributions are permissible given the stable and radiogenic isotope results (Criss and Fleck, 1990; Eaton et al., 1995). Radiogenic Pb in siderite and tetrahedrite from Ag-rich veins confirms the Sr isotope results, which indicate a Cretaceous or early Tertiary age for the Coeur d'Alene veins. Zartman and Smith (1995) have demonstrated that uranium-bearing jasper veins that predate the base- and precious-metal veins in the Sunshine mine are actually Early Cretaceous in age, not 1000-1190 Ma, as suggested by earlier workers.

Although many recent authors have invoked Proterozoic vein-forming mineralization in the Coeur d'Alene district, Cretaceous veins occupying the same structures with those of Proterozoic age and not being structurally distinct questions this conclusion. A Paleozoic or younger age is indicated for the folds and faults that contain the generally sub-planar morphology of the veins and undeformed veins of Proterozoic age are considered improbable. We find a model involving tectonic and hydrothermal re-mobilization of Proterozoic stratiform Pb-Zn deposits during the Cretaceous or early Tertiary event more credible. Isotopic results from galena- and calcite/ankerite-rich veins with high Pb and Sr concentrations are often ambiguous because of inherited "common" Sr and Pb. Just as Belt strata most likely contain a potential stratiform Pb reservoir for non-radiogenic "Coeur d'Alene-type" Pb, Belt limestones and calcareous clastic rocks are also reservoirs of Proterozoic non-radiogenic Sr. $^{87}Sr/^{86}Sr$ values less than about 0.72 in vein carbonates would be consistent with vein formation in Proterozoic time, but Mesozoic metasomatic effects could elevate these values to as much as 0.78, making age interpretations of such measurements ambiguous without other constraints.

K-Ar and Ar-Ar apparent ages of some vein muscovites are consistent with Proterozoic vein formation, but high $^{87}Sr/^{86}Sr$ in siderite from the same vein systems questions the coeval formation of the vein minerals. Although Late Cretaceous Ar-Ar apparent ages confirm the Sr and Pb isotope evidence of Mesozoic or younger mineralization, some of the Ar-Ar age spectra indicate Ar loss after Proterozoic crystallization. We acknowledge the paradox of Proterozoic Ar-Ar apparent ages on muscovite from ores that yield highly radiogenic Sr and Pb, but must conclude that wall rock mica, formed in Proterozoic time during earlier burial and metamorphism, was incorporated by Cretaceous or younger veins. As indicated by fluid inclusion studies, vein temperatures below the Ar blocking temperature of muscovite were common, permitting retention of pre-emplacement radiogenic Ar under those circumstances.

Evidence for important Cretaceous or younger Pb-Ag mineralization in the Coeur d'Alene mining district is unequivocal. Proterozoic mineralization is well documented in Belt-equivalent strata in British Columbia, but related ore bodies are most commonly described as stratiform, syngenetic, or sediment-hosted massive sulfide deposits, typified by the Sullivan-type ores (e.g. Beaudoin, 1997). Evidence for Proterozoic deformation in central Idaho and adjacent British Columbia has been documented (McMechan and Price, 1982; Evans and Fischer, 1986; Anderson and Davis, 1995; Doughty et al., 1998), although effects in northern Idaho and adjacent Montana are either minimal or unrecognized (Harrison, 1986; White 1998; 2000; White and Applegate, 2000; White et al., 2000b). Disruption, deformation, and re-mobilization of Proterozoic, Sullivan-type, syngenetic deposits into Cretaceous and early Tertiary vein systems during their emplacement could account for the Proterozoic apparent ages and Pb isotopic signatures. The study by Zartman and Smith (1995) demonstrates the mobility of the Proterozoic Pb, forming an intimate association with uranium-bearing minerals during the Cretaceous and early Tertiary metamorphic-hydrothermal event. We suggest that "Coeur d'Alene-type" Pb was mobilized from Proterozoic syngenetic deposits and incorporated into Coeur d'Alene veins with

Ag, Sr, and a variety of other metals scavenged from strata of the Belt Supergroup by Cretaceous or younger metamorphic-hydrothermal fluids.

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TABLE CAPTIONS

TABLE 1. Carbonate mineral samples from mines of the Coeur d'Alene mining district.

TABLE 2. Mean values of Sr and stable-isotope compositions of vein carbonate in the mines of the Coeur d'Alene mining district.

TABLE 3. Rb and Sr results for rocks of the Belt Supergroup.

TABLE 4. Chemical and isotopic compositions of Sr and possible sources for Coeur d'Alene veins.

TABLE 5. Location and Rb-Sr Data for High-Strontium Plutons of Washington and Idaho.

TABLE 1. Carbonate Samples From Mines Of The Coeur d'Alene District, Idaho

Sample #	Location	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$\delta^{18}O^{*}$	$\delta^{13}C^{*}$
Bullion Mine							
918-18E1	Dump, 725m NE of Bullion	0.586	3.88	0.4387	0.7580		
918-18E2	"	0.473	34.62	0.0397	0.7440	17.5	
Caladay Mine							
CAL-1	Underground	0.109	1.92	0.1669	0.8882		
CAL-2	"	0.055	2.29	0.0733	1.3256		
CAL-3	"	0.090	2.68	0.1037	1.4122		
Carbonate Hill Mine							
918-15Kak	Mine dump, east portal	0.317	60.35	0.0155	0.9074	15.6	-7.1
918-15Ksd	"	0.122	6.43	0.0565	1.0152	16.8	-7.2
Coeur Mine							
COEUR-1	Underground	0.095	4.58	0.0635	1.2913		
COEUR-2	"	0.092	2.97	0.0929	1.0865		
Galena Mine							
918-14A	3600' level, 125 vein	0.117	1.58	0.2232	1.1358	16.0	-8.5
918-14H	4000' level, Silver vein	0.094	12.37	0.0226	1.0235	17.7	-6.9
Gold Hunter Mine							
4050-14-1	4050' level,	0.071	17.56	0.0119	0.8715	17.6	-7.1
4050-15-1	"	0.092	10.52	0.0257	0.8540	17.2	-6.7
4050-15-2	"	0.135	16.14	0.0247	0.9111	16.7	-6.3
Highland Surprise							
918-17F	Mine dump, Highland Surprise	0.079	1563.	0.0001	0.8410	15.5	-7.1
Lucky Friday Mine							
918-15G	5300' level, N. Control Flt vein	0.062	6.74	0.0271	0.8570	13.7	-8.5
918-15H	5300' level, 85 vein	0.066	87.51	0.0022	0.8327	13.7	-8.1

TABLE 1. Carbonate Samples From Mines Of The Coeur d'Alene District, Idaho (Continued)

Sample #	Location	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$\delta^{18}O^{*}$	$\delta^{13}C^{*}$
Matchless Mine							
918-17C	Mine dump, Matchless Mine	0.092	687.0	0.0004	0.7396	13.6	-9.6
Sunshine Mine	Chester Vein						
42-CH-1	4200' level, Chester vein	0.084	5.98	0.0431	1.2945	15.1	-9.2
44-CH-1	4400' level, Chester vein	0.062				16.8	-6.7
50-CH-1	5000' level, Chester vein	0.053	5.37	0.0301	1.2461	14.4	-8.8
50-CH-3	5000' level, Chester vein	0.179	4.78	0.1132	1.1698		
54-CH-1	5400' level, Chester vein	0.070	4.41	0.0490	1.3170	15.6	-7.6
54-CH-3	5400' level, Chester vein	0.073	3.78	0.0578	1.1417		
56-CH-1	5600' level, Chester vein	0.060	2.71	0.0681	1.2830	14.5	-8.8
385-CH-1	3850' level, Chester vein	0.096	3.91	0.0742	1.1289	16.0	-7.1
Sunshine Mine	Copper Vein						
44-C28W-A	Traverse, Copper Vein,	0.078	8.20	0.0277	0.7921	17.2	-6.8
44-C28W-B	C28W stope, 4400' level	0.065	20.23	0.0095	0.8611	15.6	-9.3
44-C28W-C	"	0.047	1.37	0.1018	1.0831	15.6	-9.9
44-C28W-D	"	0.037	2.38	0.0457	0.9661	15.0	-9.9
44-C28W-E	"	0.054	2.43	0.0659	0.9568	15.2	-9.6
44-C28W-F	"	0.078	1.61	0.1459	1.0729	16.9	-7.5
44-C28W-G	"	1.138	1.97	1.7445	1.1550	17.0	-7.2
42-C32W-1	4200' level, Copper vein	0.261	7.32	0.1041	0.8040		
Sunshine Mine	Yankee Boy Vein						
500-1	500' level, Yankee Boy	0.239	8.16	0.0865	0.9193	15.6	-7.4
Sunshine Mine	Yankee Girl vein						
27-YG-1	2700' level, Yankee Girl vein	0.106	3.95	0.0825	1.3149	15.7	-7.2
27-YG-5	"	0.086	2.98	0.0893	1.3682	14.1	-9.6
31-YG-1	3100' level, Yankee Girl vein	0.136	3.09	0.1392	1.6260	16.3	-6.9
31-YG-3	"	0.099	4.21	0.0745	1.6408		
37-YG-1	3700' level, Yankee Girl vein	0.089	1.96	0.1429	1.5779	16.6	-6.8

TABLE 1. Carbonate Samples From Mines Of The Coeur d'Alene District, Idaho (Continued)

Sample #	Location	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$\delta^{18}O^{*}$	$\delta^{13}C^{*}$
Sunshine Mine	08 vein						
P04-08B	4000' level, 08 vein	0.273	2.88	0.2800	0.9190		
19-S-1	1900' level, 08 vein	0.351	181.4	0.0058	1.1253	13.8	-7.5
Sunshine Mine	Traverse, D-Vein						
40-P74A	P74 stope, 4000' level	1.887	2.52	2.2447	1.0769	16.8	-7.5
40-P74B		0.071	1.76	0.1212	1.1009	17.1	-7.3
40-P74C		0.097	1.55	0.1859	0.9802	16.8	-6.9
40-P74D		0.183	1.54	0.3521	0.9539	16.4	-7.5
40-P74E		0.063	1.53	0.1231	1.0488	16.7	-7.1
40-P74F		0.084	1.94	0.1293	1.0351	15.3	-8.0
40-P74G		0.060	1.68	0.1082	1.2390	15.7	-8.5
40-P74H		0.098	1.71	0.1696	0.9432	17.6	-6.9
40-P74I		0.278	2.43	0.3447	1.1320	16.8	-7.4
40-P74J		0.079	1.38	0.1697	0.9531	17.7	-6.9
40-P74K		0.088	1.89	0.1379	0.9465	16.7	-7.6
40-P74L		0.097	4.37	0.0660	0.9721		
40-P74M		0.120	1.95	0.1862	1.1548		
40-P74N		0.054	1.74	0.0944	1.2325		
40-P74O		0.056	1.83	0.0928	1.1960		
40-P74P		0.058	1.60	0.1094	1.1316		
40-P74Q		0.070	1.77	0.1182	1.1370		
Sunshine Mine							
37-R07E-1	3700' level, Rambo vein	0.076	5.62	0.0397	0.9194	17.0	-7.0
37-R05W-1		0.138	2.66	0.1537	0.9844	17.2	-6.9
Sunshine Mine							
31-S-1	3100' level, Sunshine vein	0.244	11.67	0.0618	0.9324	14.9	-8.1
34-S-2	3400' level, Sunshine vein	0.245	5.57	0.1299	0.9250	14.9	-7.3

* $\delta^{18}O$ and $\delta^{13}C$ values are reported in permil (‰).

TABLE 2. Summary of Results for Mines of the Coeur D'Alene District

Location	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$\delta^{18}O$*	$\delta^{13}C$*
Bullion Mine	0.529	19.25	0.2392	0.7510	17.5	-3.7
Caladay Mine	0.084	2.30	0.1146	1.2087		
Coeur Mine	0.093	3.78	0.0782	1.1889		
Galena Mine	0.105	6.98	0.1229	1.0797	16.8	-7.7
Carbonate Hill Mine	0.220	33.39	0.0360	0.9613	16.2	-7.2
Gold Hunter Mine	0.099	14.74	0.0207	0.8789	17.2	-6.7
Lucky Friday Mine	0.064	47.12	0.0147	0.8448	13.7	-8.3
Highland Surprise Mine	0.079	1563.	0.0001	0.8410	15.5	-7.1
Matchless Mine	0.092	687.	0.0004	0.7396	13.6	-9.6
Chester vein	0.085	4.42	0.0622	1.2259	15.4	-8.0
Copper vein	0.220	5.69	0.2807	0.9614	16.1	-8.6
Yankee Boy vein	0.239	8.16	0.0865	0.9193	15.6	-7.4
Yankee Girl vein	0.103	3.24	0.1057	1.5056	15.7	-7.6
08 vein	0.312	92.17	0.1429	1.0221	13.8	-7.5
D-vein	0.202	1.95	0.2796	1.0726	16.7	-7.4
Rambo vein	0.107	4.14	0.0967	0.9519	17.1	-7.0
Sunshine vein	0.245	8.62	0.0959	0.9287	14.9	-7.7
Mean of All Veins	0.175	86.31	0.111	1.018	15.8	-7.4

* $\delta^{18}O$ and $\delta^{13}C$ values are reported in permil (‰).

TABLE 3. Rb and Sr Results for Rocks of the Belt Supergroup.

Sample #	Latitude	Longitude	Rock Type	Unit	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model Age^{+}
858-6A	47°49.63'	116°40.57'	Quartzite	Wallace	97.3	3.7	26.114	47.1796	1.2701	838
6C	47°49.53'	116°40.46'	Bi-Mu Schist	Wallace	238.9	9.2	26.092	78.8435	1.1613	406
6D	47°50.65'	116°39.43'	Argillite	Wallace	276.8	17.0	16.271	50.2589	1.3994	966
6E	47°50.75'	116°39.33'	Argillite	Wallace	176.1	10.2	17.239	53.5341	1.4612	988
6F	47°51.46'	116°39.16'	Argillite	Wallace	154.7	5.5	28.175	87.3447	1.4385	589
6G	47°48.14'	116°37.61'	Quartzite	Revett	194.1	61.2	3.171	9.2937	0.8410	1023
6H	47°47.93'	116°36.25'	Argillite	Wallace	137.9	16.7	8.239	24.4463	0.9584	726
6I	47°47.58'	116°34.80'	Argillite	Wallace	117.4	45.6	2.573	7.5234	0.8174	1044
6J	47°47.31'	116°30.67'	Siltite	Burke	171.2	74.4	2.302	6.7472	0.8410	1405
6K	47°47.31'	116°30.67'	Siltite	Burke	146.8	42.2	3.478	10.2455	0.8928	1279
6L	47°46.91'	116°29.49'	Calc Argillite	Wallace	92.3	81.2	1.136	3.3085	0.7743	1460
6M	47°48.00'	116°28.44'	Shale	Wallace	151.9	14.2	10.713	32.5280	1.2130	1091
6N	47°44.66'	116°26.03'	Quartzite	Wallace	77.9	130.8	0.596	1.7302	0.7477	1717
6P	47°44.66'	116°26.03'	Argillite	Wallace	188.4	96.7	1.948	5.6954	0.8125	1317
6Q	47°44.22'	116°21.37'	Argillite	Wallace	195.8	30.6	6.399	19.0300	0.9927	1057
6R	47°44.22'	116°21.37'	Argillite	Wallace	118.0	30.9	3.815	11.2179	0.8745	1056
6S	47°37.80'	116°16.86'	Quartzite	Wallace	67.6	54.4	1.243	3.6167	0.7695	1245
6T	47°37.80'	116°16.86'	Argillite	Wallace	210.8	39.0	5.399	15.9306	0.9089	896
7A	47°36.54'	116°14.05'	Shale	Wallace	345.6	13.1	26.479	84.1860	1.7179	842
7B	47°36.54'	116°14.05'	Argillite	Wallace	169.3	36.9	4.595	13.5894	0.9348	1181
7C	47°38.19'	116°11.42'	Quartzite	Wallace	69.9	62.9	1.111	3.2341	0.7737	1480
7D	47°38.19'	116°11.42'	Argillite	Wallace	151.1	32.8	4.605	13.5747	0.9093	1052
7E	47°41.44'	116°09.59'	Quartzite	Wallace	71.6	94.8	0.756	2.1969	0.7543	1563
7F	47°41.50'	116°09.62'	Argillite	Wallace	181.9	25.1	7.257	21.7124	1.0564	1131
7G	47°39.19'	116°01.79'	Quartzite	Wallace	23.3	125.9	0.185	0.5365	0.7402	4475
7H	47°39.19'	116°01.79'	Argillite	Wallace	220.2	32.3	6.811	20.3270	1.2096	1727
7I	47°47.52'	116°04.00'	Shale	Wallace	207.9	37.0	5.621	16.7395	1.0077	1262
7J	47°47.52'	116°04.00'	Argillite	Wallace	180.9	45.9	3.940	11.6430	0.9272	1331
7K	47°42.05'	115°56.54'	Siltite	St. Regis	81.0	90.4	0.896	2.6075	0.7639	1573
7L	47°41.82'	115°57.07'	Quartzite	Wallace	32.7	455.5	0.072	0.2079	0.7294	7816
7M	47°41.82'	115°57.07'	Argillite	Wallace	207.2	22.4	9.258	28.0368	1.1849	1195
7N	47°35.82'	115°56.16'	Argillite	Wallace	175.3	23.2	7.567	22.5888	1.0285	1001

TABLE 3. Rb and Sr Results for Rocks of the Belt Supergroup (Continued).

Sample #	Latitude	Longitude	Rock Type	Unit	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model Age
858-7P	47°35.82'	115°56.16'	Quartzite	Wallace	32.3	165.8	0.195	0.5646	0.7269	2680
7Q	47°33.58'	115°55.27'	Shale	Wallace	181.8	49.8	3.652	10.7540	0.8903	1203
7R	47°33.57'	115°55.34'	Argillite	Wallace	143.3	98.3	1.457	4.2466	0.7808	1246
7S	47°24.71'	115°53.42'	Siltite	Wallace	231.1	14.4	16.009	49.6911	1.4549	1055
7T	47°24.40'	115°53.11'	Argillite	Wallace	184.6	28.9	6.382	18.9888	0.9976	1077
7U	47°21.38'	115°53.24'	Argillite	Wallace	163.4	31.4	5.208	15.3773	0.9185	971
7V	47°21.38'	115°53.24'	Quartzite	Wallace	50.8	55.1	0.921	2.6913	0.8074	2630
7W	47°19.58'	115°55.04'	Quartzite	Wallace	75.2	21.2	3.553	10.4422	0.8700	1104
7X	47°19.58'	115°55.04'	Shale	Wallace	230.6	19.5	11.802	35.4564	1.0996	779
8A	47°24.81'	115°50.27'	Quartzite	Wallace	69.5	66.7	1.042	3.0315	0.7759	1628
8B	47°24.81'	115°50.27'	Argillite	Wallace	186.6	54.0	3.457	10.1632	0.8719	1147
8C	47°21.67'	115°44.21'	Quartzite	Wallace	51.0	60.5	0.842	2.4509	0.7704	1855
8D	47°21.67'	115°44.21'	Limestone	Wallace	32.8	262.7	0.125	0.3622	0.7378	6105
8E	47°19.03'	115°45.82'	Argillite	Wallace	203.0	47.2	4.298	12.6709	0.9018	1085
8F	47°17.14'	115°46.26'	Shale	Wallace	262.6	191.3	1.373	3.9965	0.7731	1190
8G	47°16.71'	115°46.28'	Shale	Wallace	204.1	67.4	3.028	8.8794	0.8473	1120
8H	47°15.78'	115°47.38'	Slate	Wallace	89.0	120.8	0.737	2.1441	0.7710	2135
8I	47°15.15'	115°47.76'	Quartzite	Wallace	115.0	37.2	3.089	9.0546	0.8432	1067
8L	47°10.59'	115°29.93'	Calc Argillite	Wallace	134.5	48.2	2.791	8.2054	0.8735	1432
8M	47°10.10'	115°30.34'	Quartzite	Wallace	12.5	32.4	0.387	1.1270	0.7627	3516
8N	47°09.78'	115°31.58'	Quartzite	Wallace	119.5	85.7	1.394	4.0696	0.7994	1615
8P	47°09.11'	115°32.12'	Quartzite	Wallace	33.8	45.9	0.735	2.1378	0.7576	1712
8Q	47°08.81'	115°33.28'	Argillite	Wallace	127.4	96.4	1.322	3.8532	0.7854	1454
8R	47°07.55'	115°35.28'	Quartzite	Wallace	69.0	36.3	1.902	5.5554	0.8053	1260
8S	47°09.46'	115°38.19'	Shale	Wallace	183.3	50.6	3.619	10.6546	0.8928	1230
8T	47°09.46'	115°38.19'	Quartzite	Wallace	111.1	58.4	1.902	5.5492	0.7945	1127
8U	47°10.15'	115°39.23'	Quartzite	Wallace	96.7	77.4	1.248	3.6446	0.8013	1837
8V	47°10.15'	115°39.23'	Argillite	Wallace	154.3	102.1	1.511	4.4099	0.7944	1413
8W	47°11.91'	115°30.52'	Quartzite	Wallace	12.6	2.1	5.983	17.4941	0.8169	449
8X	47°11.95'	115°30.58'	Argillite	Wallace	204.2	33.5	6.100	17.8882	0.8455	551
8Y	47°13.51'	115°34.92'	Quartzite	Wallace	38.5	28.4	1.355	3.9477	0.7774	1280
8Z	47°13.51'	115°34.92'	Shale	Wallace	172.8	50.0	3.456	10.1696	0.8750	1167

TABLE 3. Rb and Sr Results for Rocks of the Belt Supergroup (Continued).

Sample #	Latitude	Longitude	Rock Type	Unit	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model Age
858-8AA	47°14.56'	115°38.58'	Quartzite	Wallace	45.6	57.7	0.791	2.3099	0.8065	3028
8AB	47°14.56'	115°38.58'	Argillite	Wallace	237.3	19.3	12.285	36.6022	1.0120	588
8AD	47°13.72'	115°42.45'	Argillite	Wallace	197.7	36.4	5.435	16.1570	0.9878	1222
9A	47°30.34'	116°04.28'	Quartzite	Revett	281.8	8.8	32.110	104.0420	1.9335	827
9B	47°30.28'	116°04.63'	Quartzite	Revett	113.8	5.9	19.452	61.3530	1.6319	1056
9C	47°30.13'	116°04.23'	Argillite	St. Regis	253.1	8.6	29.519	92.1990	1.5202	620
9D	47°27.32'	116°04.40'	Quartzite	Wallace	75.6	43.8	1.728	5.0514	0.8130	1490
9E	47°27.32'	116°04.40'	Argillite	Wallace	324.6	20.0	16.220	49.3552	1.2363	754
9F	47°16.37'	115°07.92'	Slate	Wallace	85.5	208.0	0.411	1.1934	0.7473	2453
9G	47°16.37'	115°07.92'	Slate	Wallace	7.0	23.4	0.300	18.5089	0.8850	682
9H	47°14.35'	115°13.36'	Slate	Wallace	184.8	49.4	3.743	10.9526	0.8228	753
9I	47°14.29'	115°13.32'	Siltite	Wallace	126.8	87.5	1.449	4.2176	0.7697	1072
9J	47°13.57'	115°18.01'	Slate	Wallace	181.2	37.0	4.894	14.3596	0.8524	719
9K	47°13.57'	115°18.01'	Quartzite	Wallace	85.0	212.9	0.400	1.1608	0.7503	2696
9L	47°13.47'	115°21.20'	Argillite	Wallace	239.8	25.1	9.563	28.0847	0.8631	395
9M	47°13.47'	115°21.20'	Quartzite	Wallace	70.7	39.3	1.800	5.2627	0.8156	1465
9P	47°05.73'	115°22.67'	Quartzite	Wallace	178.1	51.6	3.454	10.1186	0.8331	886
9Q	47°05.73'	115°22.67'	Quartzite	Wallace	61.7	34.7	1.780	5.2171	0.8400	1799
9R	47°09.50'	115°23.67'	Quartzite	Wallace	137.8	89.8	1.533	4.4883	0.8270	1889
9S	47°09.50'	115°23.67'	Quartzite	Wallace	42.4	12.9	3.285	9.6034	0.8137	793
10B	46°29.26'	115°42.46'	Bi-Mu Schist	Wallace	252.1	45.7	5.517	15.9980	0.7303	111
10D	46°31.46'	115°39.63'	Bi-Mu Schist	Wallace	114.9	72.9	1.577	4.5794	0.7482	661
10H	46°29.18'	115°40.23'	Bi-Mu Schist	Wallace	120.1	23.1	5.191	14.7100	0.7302	121
11A	46°37.20'	115°47.71'	Bi-Mu Schist	Wallace	277.0	97.0	2.857	8.3125	0.7810	641
11B	46°37.20'	115°47.71'	Bi-Mu Schist	Wallace	194.2	90.3	2.151	6.2560	0.7635	655
11C	46°35.18'	115°50.02'	Bi Schist	Wallace	112.4	192.7	0.583	1.6924	0.7334	1172
918-12A	47°25.62'	116°12.83'	Quartzite	Revett	95.1	9.52	9.989	30.4477	1.2543	1259
12B	47°25.17'	116°12.30'	Argillite	St. Regis	249	27.5	9.055	27.3842	1.1709	1188
12C	47°24.95'	116°11.20'	Siltite	Wallace	136	62.4	2.179	6.3871	0.8395	1467
12D	47°24.95'	116°11.20'	Quartzite	Wallace	50.6	38.0	1.332	3.8846	0.7926	1570
12E	47°24.85'	116°12.43'	Argillite	St. Regis	212	12.6	16.825	52.7259	1.5573	1129
12F	47°24.41'	116°12.66'	Siltite	St. Regis	148	31.5	4.698	13.9125	0.9474	1216

TABLE 3. Rb and Sr Results for Rocks of the Belt Supergroup (Continued).

Sample #	Latitude	Longitude	Rock Type	Unit	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model Age
918-12G	47°24.41'	116°12.66'	Quartzite	St. Regis	141	28.6	4.930	14.6230	0.9650	1241
12H	47°25.04'	116°16.06'	Quartzite	Revett	120	9.08	13.216	40.4972	1.3120	1048
12I	47°30.13'	116°04.23'	Argillite	St. Regis	186	8.19	22.711	69.6763	1.3251	624
13A	47°28.72'	115°57.96'	Argillite	St. Regis	357	3.20	111.423	368.2909	2.1636	278
13B	47°28.72'	115°57.96'	Quartzite	St. Regis	126	31.9	3.950	11.8468	1.0824	2209
13C	47°29.08'	115°57.70'	Limestone	Wallace	17.6	318.5	0.055	0.1608	0.7681	23312
13D	47°29.08'	115°57.70'	Shale	Wallace	154	30.41	5.064	14.9453	0.9118	968
13E	47°29.08'	115°57.70'	Quartzite	Wallace	44.5	63.9	0.696	2.0291	0.7798	2549
13F	47°32.00'	116°03.34'	Siltite	Prichard	170	81.4	2.088	6.1125	0.8262	1383
13G	47°30.37'	115°52.41'	Monzonite	Gem Stock	221	1244.5	0.178	0.5137	0.7056	79
13H	47°30.39'	115°52.37'	Monzonite	Gem Stock	130	1384.9	0.094	0.2715	0.7055	123
13I	47°30.10'	115°52.83'	Siltite	Prichard	225	40.8	5.515	16.2681	0.9080	873
13J	47°31.95'	115°52.06'	Monzonite	Gem Stock	143	1500	0.095	0.2758	0.7059	225
13K	47°32.28'	115°51.68'	Granite	Pegmatite	707	36.53	19.354	56.5686	0.8122	133
13M	47°32.14'	115°52.85'	Argillite	Prichard	194	44.8	4.330	12.7238	0.8668	890
14B	47°28.41'	115°57.51'	Quartzite	Revett	82.6	5.74	14.390	44.3710	1.3795	1063
14D	47°28.42'	115°57.59'	Quartzite	Revett	70.8	6.63	10.679	32.6102	1.2748	1220
14K	47°28.55'	115°57.90'	Quartzite	Revett	114	6.85	16.642	52.1016	1.5465	1128
14L	47°38.06'	115°58.72'	Quartzite	Revett	67.7	6.41	10.562	32.2493	1.2737	1231
14M	47°35.65'	115°47.83'	Siltite	Prichard	209	65.8	3.176	9.3181	0.8504	1090
14N	47°36.05'	115°47.72'	Siltite	Prichard	172	71.1	2.419	7.0780	0.8228	1163
14P	47°37.52'	115°51.09'	Siltite	Prichard	191	47.3	4.038	11.8760	0.8765	1009
14Q	47°41.29'	115°46.35'	Siltite	Prichard	174	86.2	2.019	5.9049	0.8210	1370
15D	47°28.17'	115°46.84'	Quartzite	Revett	46.2	26.7	1.730	5.2730	1.2522	6953
15J	47°28.08'	115°45.83'	Shale	Wallace	194	26.7	7.266	21.5890	0.9833	902
15L	47°27.06'	115°46.08'	Shale	St. Regis	194	13.5	14.370	43.7870	1.2510	873
15M	47°27.06'	115°46.08'	Quartzite	St. Regis	49.1	27.3	1.799	5.3741	1.0426	4291
16A	47°29.60'	115°58.35'	Argillite	Wallace	233	22.2	10.495	31.3957	1.0543	779
16B	47°23.29'	115°48.66'	Argillite	Wallace	298	13.3	22.406	70.6887	1.6321	918
16C	47°20.49'	115°37.48'	Argillite	Wallace	232	13.1	17.710	53.2287	1.1046	527
16D	47°20.79'	115°44.22'	Siltite	Wallace	151	43.3	3.487	10.2719	0.8923	1273
16E	47°18.67'	115°45.95'	Phyllite	Wallace	197	58.8	3.350	9.8360	0.8581	1088

TABLE 3. Rb and Sr Results for Rocks of the Belt Supergroup (Continued).

Sample #	Latitude	Longitude	Rock Type	Unit	Rb	Sr	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Model Age
918-16F	47°15.12'	115°50.69'	Argillite	Wallace	178	48.8	3.646	10.7071	0.8618	1024
16G	47°15.37'	115°55.33'	Argillite	Wallace	178	69.2	2.572	7.5273	0.8246	1110
16H	47°18.39'	115°55.51'	Slate	Wallace	470	12.4	37.903	116.4794	1.3430	385
16I	47°17.20'	115°55.95'	Argillite	Wallace	173	13.7	12.628	37.4142	0.9536	466
16J	47°16.23'	115°55.93'	Argillite	Wallace	195	14	13.929	41.6782	1.0576	593
16K	47°16.02'	116°04.61'	Granite	Pluton	86.8	409	0.212	0.6145	0.7161	1259
16M	47°17.63'	116°07.42'	Argillite	Wallace	124	57.1	2.172	6.3876	0.8778	1880
17A	47°31.19'	116°14.45'	Siltite	Prichard	156	56.0	2.786	8.1582	0.8325	1092
17B	47°30.67'	116°14.48'	Shale	Prichard	253	35.9	7.047	20.8578	0.9423	797
17D	47°28.82'	116°14.80'	Argillite	Prichard	192	70	2.743	8.0397	0.8416	1186
17E	47°28.84'	116°09.75'	Argillite	Prichard	197	49.9	3.948	11.5995	0.8663	972
17H	47°27.20'	116°10.89'	Argillite	Prichard	231	60.5	3.818	11.2658	0.9102	1271
17I	47°22.02'	116°10.98'	Argillite	Striped Peak	252	29.2	8.630	25.8217	1.0567	953
17J	47°20.46'	116°09.73'	Argillite	Striped Peak	260	14.2	18.310	56.7856	1.4430	909
17K	47°19.04'	116°09.17'	Argillite	Wallace	213	16.74	12.723	37.8705	1.0017	550
17L	47°20.66'	116°37.01'	Siltite	Wallace	126	31.1	4.051	11.8242	0.7970	546
17M	47°25.62'	116°37.51'	Argillite	Wallace	236	139	1.698	4.9552	0.7970	1295
17N	47°32.12'	116°30.64'	Siltite	Burke	150	69.85	2.148	6.2757	0.8099	1167
18A	47°28.05'	115°50.68'	Argillite	St. Regis	214	27.70	7.726	23.1272	1.0610	1076
18B	47°27.59'	115°43.39'	Phyllite	St. Regis	158	33.73	4.684	13.7546	0.8603	791
18C	47°24.39'	115°41.73'	Argillite	Wallace	163	31.7	5.142	15.2249	0.9467	1109
18D	47°24.39'	115°41.73'	Argillite	Wallace	250	12.71	19.676	60.1141	1.2800	670

+ Model ages are reported in Ma and assume an initial $^{87}Sr/^{86}Sr$ ratio of Mesoproterozoic seawater of 0.705 (Mirota and Veizer, 1994).

TABLE 4. Compositions of Possible Sources of Coeur d'Alene Veins

	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
Belt Supergroup, Metasedimentary Rocks [1]				
Average	160	60	15.27	0.925
Median	158	47	9.64	0.862
Belt Supergroup, Carbonate Rocks [2]	11	95	0.34	0.714
Archean Amphibolite [3]				
Average	19	178	0.392	0.719
Median	8	127	0.305	0.717
Archean Granitoid Rocks [4]				
Average	75	294	1.321	0.760
Median	62	260	0.768	0.740

[1] Obradovich and Peterman (1968), Criss and Fleck (1987), and Fleck, R.J. (unpublished measurements)

[2] Obradovich and Peterman (1968) and Fleck (unpublished measurements)

[3] Mogk and others, 1988, 1992, and Wooden and Mueller, 1988

[4] Henry and others, 1982, and Wooden and Mueller, 1988, Mogk and others, 1992, Mueller and others, 1993.

TABLE 5. Location and Rb-Sr Data for High-Strontium Plutons of Washington and Idaho

Sample #	Latitude	Longitude	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	Age (Ma)	Sri
Gem Stocks								
918-13G	47°30'21.9"N	115°52'24.6"W	221	1245	0.3995	0.70558	110	0.7050
918-13H	47°30'23.3"N	115°52'22.5"W	130	1385	0.2293	0.70548	110	0.7051
918-13J	47°31'57.2"N	115°52'04.0"W	143	1500	0.2758	0.70588	110	0.7054
Silver Point Granite and Other Plutons of Northern Washington and Idaho								
837-8A	48°15'10.8"N	116°36'35.4"W	75.3	1078	0.2020	0.70539	50	0.7052
837-8C	48°15'38.0"N	116°19'44.4"W	78.4	1254	0.1809	0.70569	52	0.7056
837-10A	48°08'20.8"N	117°10'57.4"W	102.0	1165	0.2533	0.70561	52	0.7054
837-10B	48°05'52.3"N	117°18'18.0"W	94.5	1489	0.1836	0.70571	52	0.7056
837-10C	48°05'52.7"N	117°18'15.1"W	98.6	1135	0.2513	0.70595	52	0.7058
877-28F	48°14'03.0"N	116°41'49.8"W	52.6	1345	0.1131	0.70537	50	0.7053
877-29D	48°12'46.6"N	117°17'22.2"W	79.6	1697	0.1357	0.70578	52	0.7057

FIGURE CAPTIONS

Figure 1. Location of the Coeur d'Alene mining district in northern Idaho and distribution of major mines. Symbols show approximate locations of mines referred to in the text: B, Bullion; BH, Bunker Hill; C, Coeur; CA, Caladay; CH, Carbonate Hill; G, Galena; GH, Gold Hunter; HS, Highland Surprise; LF, Lucky Friday; M, Matchless; S, Sunshine; SC, Success; SM, Star-Morning; SS, Silver Summit. Sampled ore-bodies are identified in Table 1.

Figure 2. Rb-Sr correlation diagram of carbonate minerals of the Coeur d'Alene mining district. Note that a 1600-Ma reference isochron appears near the X axis and that all analyses of vein carbonates lie above it in a generally random distribution.

Figure 3. Rb-Sr correlation diagram of mean $^{87}Sr/^{86}Sr$ and 1/Sr values of carbonate minerals from individual vein systems of the Coeur d'Alene mining district. The inverse correlation of $^{87}Sr/^{86}Sr$ with Sr in the veins probably reflects a mixing of low-Sr, high-$^{87}Sr/^{86}Sr$ fluids derived from old, high-Rb/Sr sources with those leached from high-Sr, marine carbonate rocks.

Figure 4. Correlation diagram of mean $\delta^{13}C$ and $\delta^{18}O$ results for carbonate minerals from individual vein systems of the Coeur d'Alene mining district, Idaho. Positive correlation of $\delta^{13}C$ and $\delta^{18}O$ is typical of the covariation of these isotopic systems in other carbonate-gangue ore deposits.

Figure 5. Stable-isotope, 1/Sr, and $^{87}Sr/^{86}Sr$ results for siderite from a sample traverse (10 cm spacing) of the Copper vein in the Sunshine Mine documents the covariation of $\delta^{18}O$ and $\delta^{13}C$. The smooth decrease in both stable isotopes from wall to center suggests an inward progressing crystallization of the vein during steadily increasing fluid temperature (Eaton et al., 1995). Variations in Sr show no apparent correlation with stable isotope variations, but exhibit a strong correlation of 1/Sr and $^{87}Sr/^{86}Sr$. This inverse correlation between Sr and $^{87}Sr/^{86}Sr$ indicates a mixing relationship between

components with high Sr, low $^{87}Sr/^{86}Sr$ (such as Belt limestone or dolomite) and low Sr, high $^{87}Sr/^{86}Sr$ (such as radiometrically evolved Belt argillite). Both correlated variations are consistent with primary crystallization from vein fluids and inconsistent with post-depositional metamorphic homogenization.

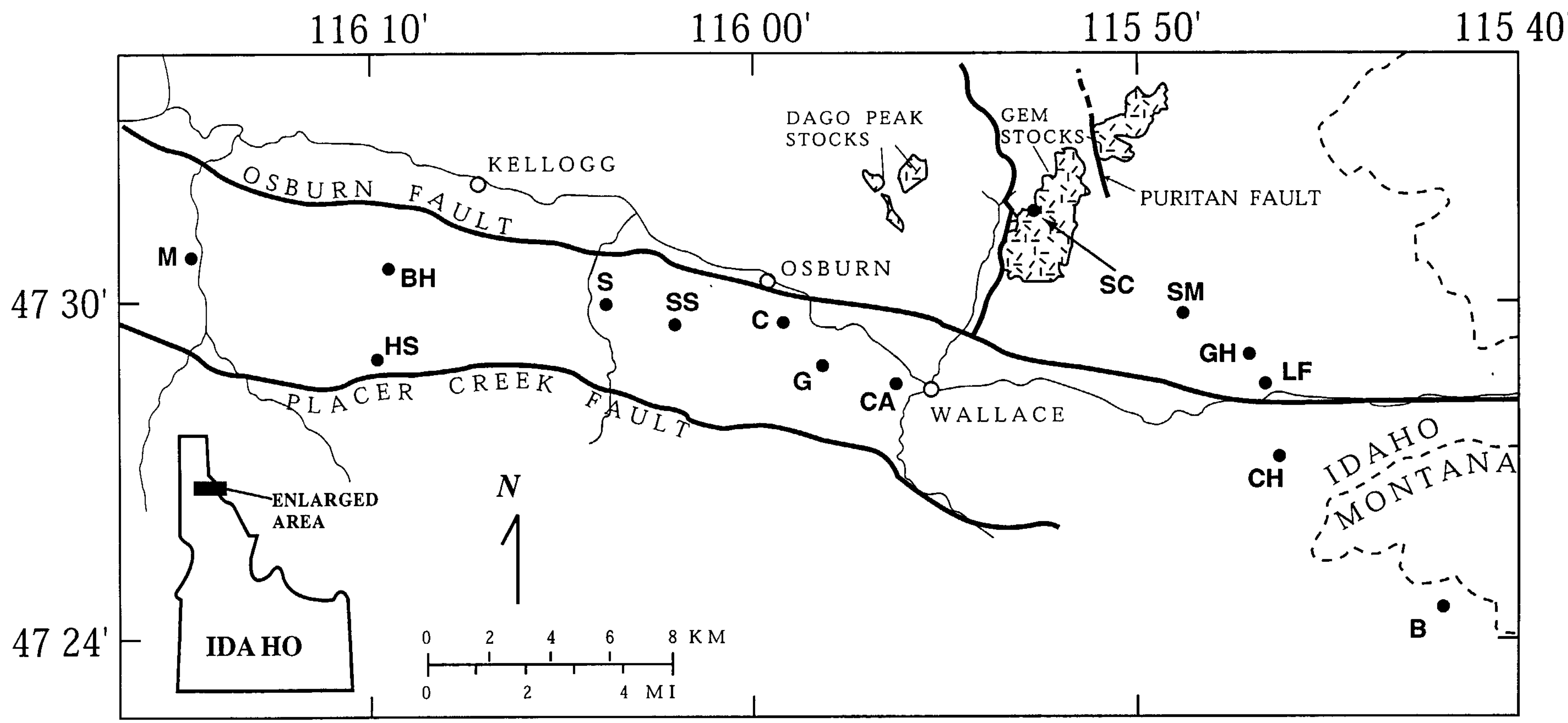
Figure 6. Stable-isotope and $^{87}Sr/^{86}Sr$ sample traverses (10 cm spacing) of the D-vein in the Sunshine Mine show patterns of vein deposition with very large, irregular fluctuations in siderite isotopic composition. Co-variation in $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ document a clear but inexact anti-correlation of the two chemically and isotopically unrelated species. The same inverse relationship is even apparent in the faulted portion of the vein. Because a pressure/temperature control of Sr isotope variation is highly improbable, the well-established pattern of stable-isotope fractionation may have been superimposed on source-related isotopic variations in the fluids during the course of vein formation. Regardless of the control of fluid composition, however, the isotopic variations appear to be primary fluid phenomena, with the same interrelationship throughout the period this vein was being deposited. Note that $\delta^{18}O$ values in the adjacent Revett Formation host rocks are below those of the vein, but that host-rock values increase toward the vein. Isotopic disequilibrium is found not only between the vein and host, but also between vein minerals, precluding a post-depositional metasomatic metamorphism that would homogenize isotopic ratios. Faulting in the vein documents post-emplacement deformation, repeating a part of the vein..

Figure 7. Comparison of measured $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ in rocks of the Belt Supergroup and separated carbonate minerals from veins of the Coeur d'Alene mining district. Note that the extreme $^{87}Sr/^{86}Sr$ values established in the vein carbonates during ore deposition is only matched by the highest $^{87}Sr/^{86}Sr$ values of *present-day* Belt strata.

Figure 8. Comparison of $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values calculated for rocks of the Belt Supergroup and Coeur d'Alene carbonate vein minerals as they would have been 850 m.y. ago. Because the $^{87}Sr/^{86}Sr$ of the carbonates is virtually unchanged in 850 m.y.

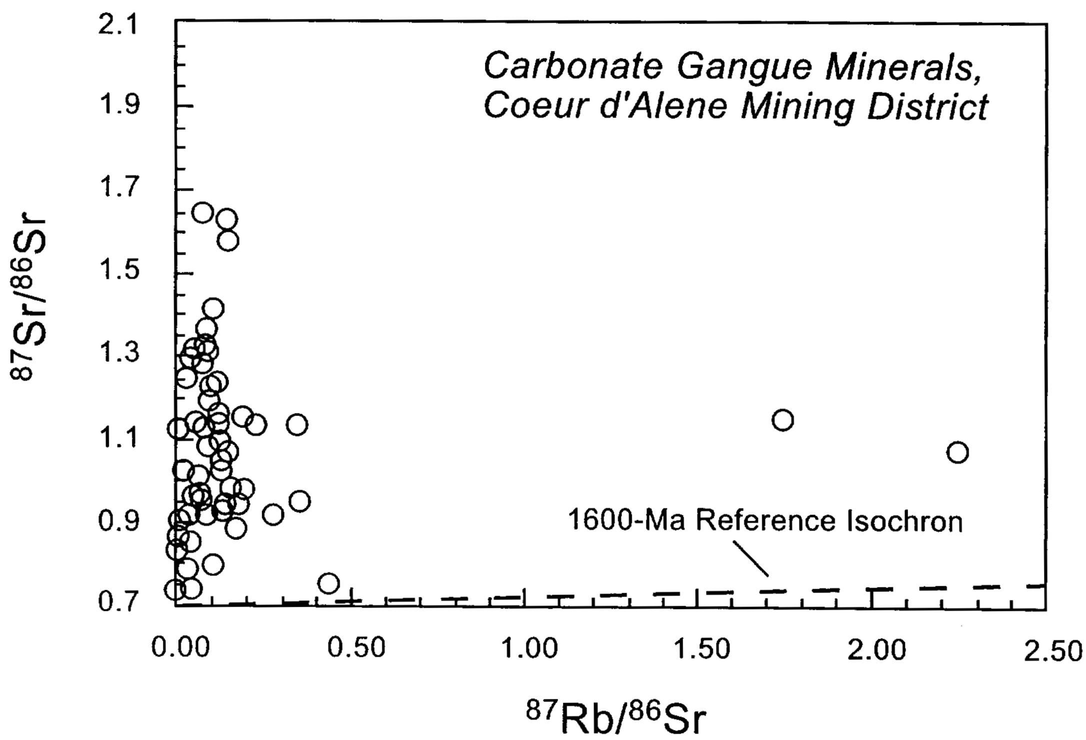
due to their minimal Rb contents, whereas the high-Rb/Sr Belt strata have increased as shown, Belt rocks could not have been the source of the highly radiogenic vein Sr at 850 Ma or earlier. As discussed in the text, no other sources in northern Idaho would have had sufficiently elevated $^{87}Sr/^{86}Sr$ to produce the values observed in the veins. Consequently, the veins must have formed much more recently, probably in Cretaceous time.

Figure 9. $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ values calculated at 850 m.y. ago for Archean rocks from western Montana and eastern Washington compared to the same parameters calculated for carbonate vein minerals of the Coeur d'Alene mining district. Although Rb-Sr whole-rock isochron ages calculated for the Archean rocks (James and Hedge, 1980; Henry et al., 1982; Wooden and Mueller, 1988; Mock et al., 1988; Mueller et al., 1993) yield values ranging from 3400 Ma to 2600 Ma, Rb/Sr ratios of these rocks are much less than rocks of the Belt Supergroup, which by 850 Ma had reached similar $^{87}Sr/^{86}Sr$ values. Note that neither group has sufficiently radiogenic $^{87}Sr/^{86}Sr$ at 850 Ma to provide the values as high as 1.6 measured in the ore-bearing veins. Increasing the age of mineralization to 1000 Ma, as proposed by Rosenberg and Larson (1996) and Leach et al. (1998), would result in even lower $^{87}Sr/^{86}Sr$ in either the Archean or Belt rocks and make them even less appropriate as sources of the radiogenic Sr. As shown, only in late Phanerozoic time have $^{87}Sr/^{86}Sr$ ratios in the Belt strata reached appropriate levels.



116 10'
116 00'
115 50'
115 40'
47 30'
47 24'
KELLOGG
OSBURN FAULT
OSBURN
DAGO PEAK STOCKS
GEM STOCKS
PURITAN FAULT
PLACER CREEK FAULT
WALLACE
IDAHO
MONTANA
M
BH
HS
S
SS
C
G
CA
SC
SM
GH
LF
CH
B
N
0 2 4 6 8 KM
0 2 4 MI
ENLARGED AREA
IDA HO

Figure 1



Carbonate Gangue Minerals,
Coeur d'Alene Mining District
1600-Ma Reference Isochron
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.00
0.50
1.00
1.50
2.00
2.50
87Sr/86Sr
87Rb/86Sr

Figure 2

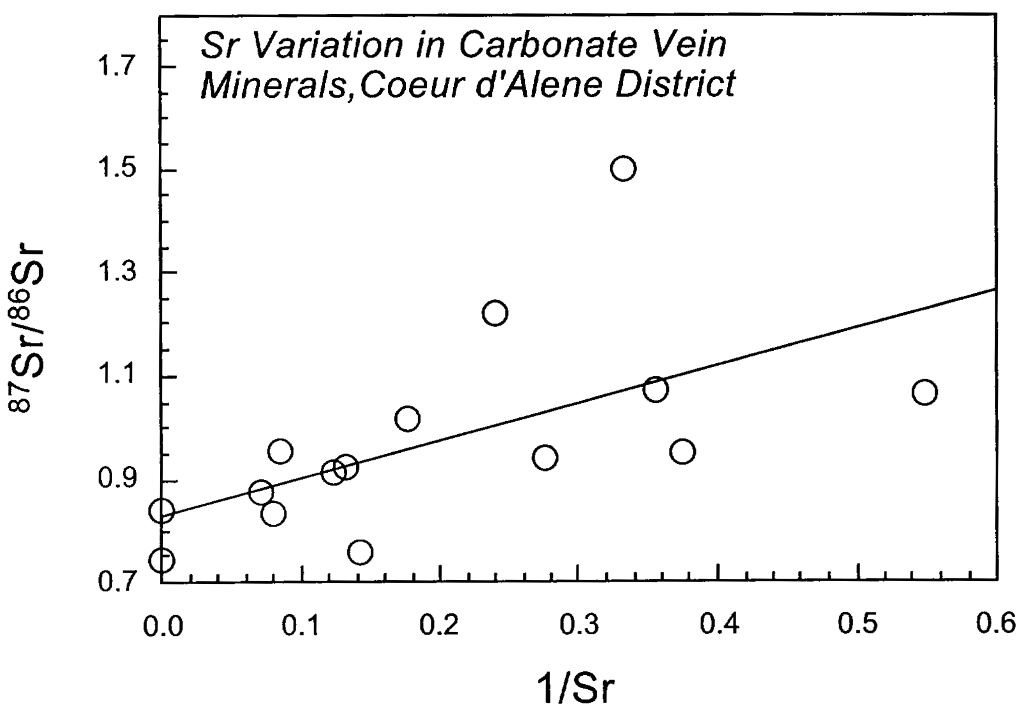

Sr Variation in Carbonate Vein
Minerals, Coeur d'Alene District
1.7
1.5
1.3
1.1
0.9
0.7
$^{87}Sr/^{86}Sr$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1/Sr

Figure 3

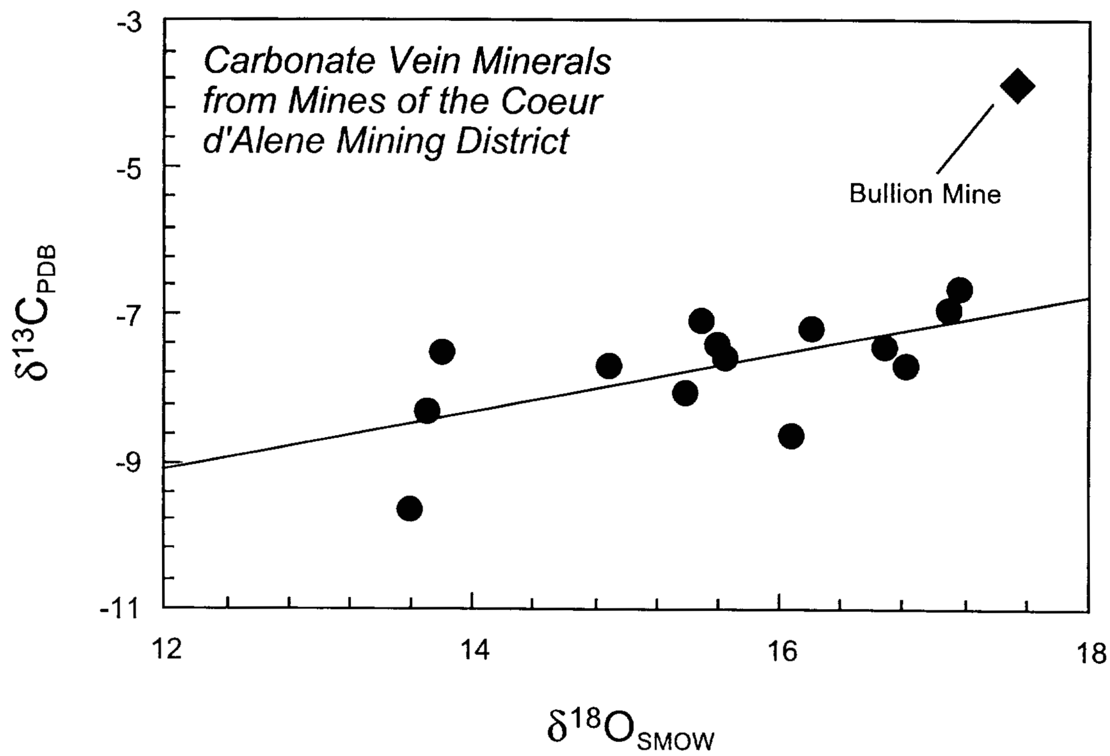

Carbonate Vein Minerals
from Mines of the Coeur
d'Alene Mining District
Bullion Mine
-3
-5
-7
-9
-11
12
14
16
18
$\delta^{18}O_{SMOW}$
$\delta^{13}C_{PDB}$

Figure 4

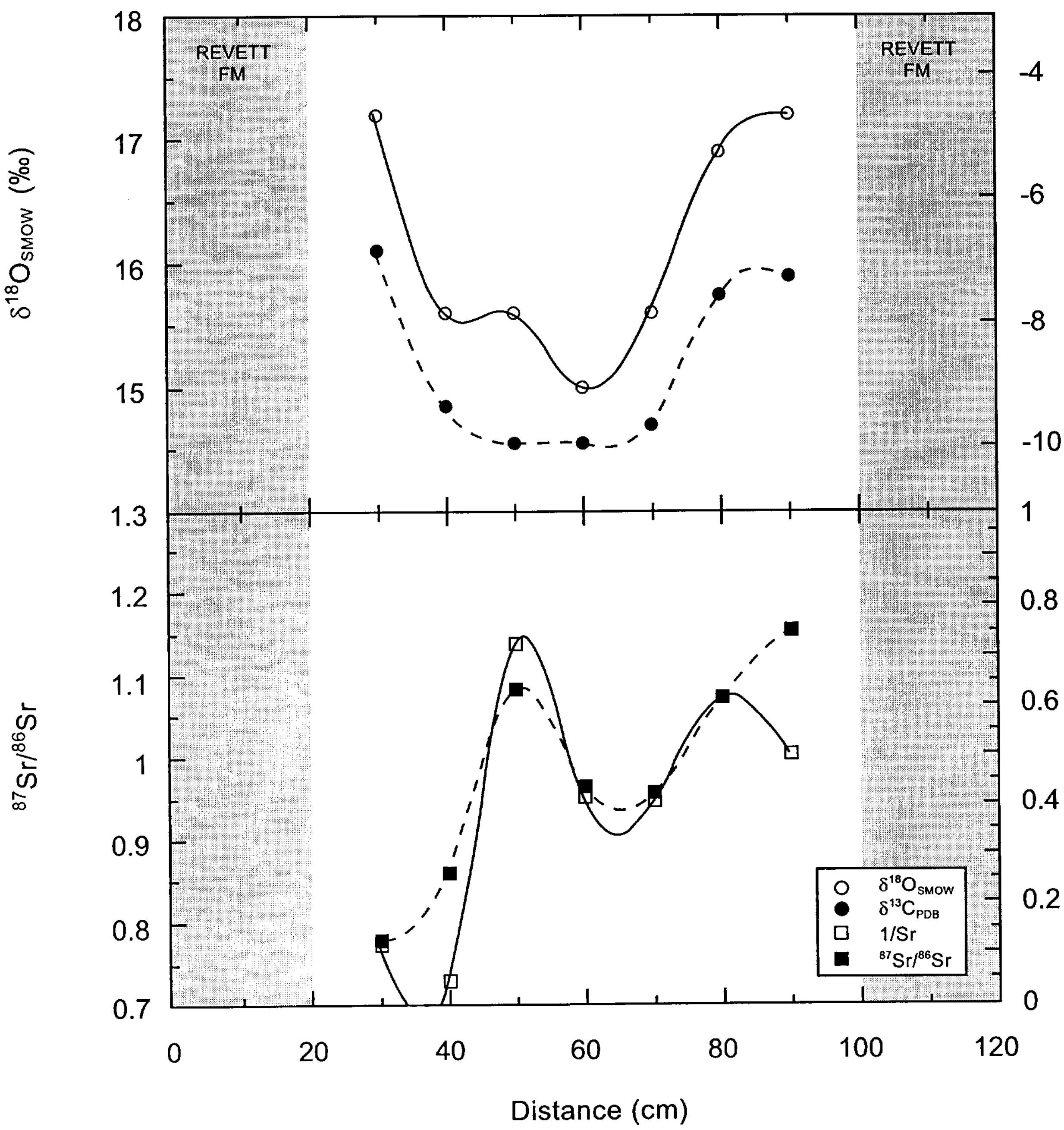
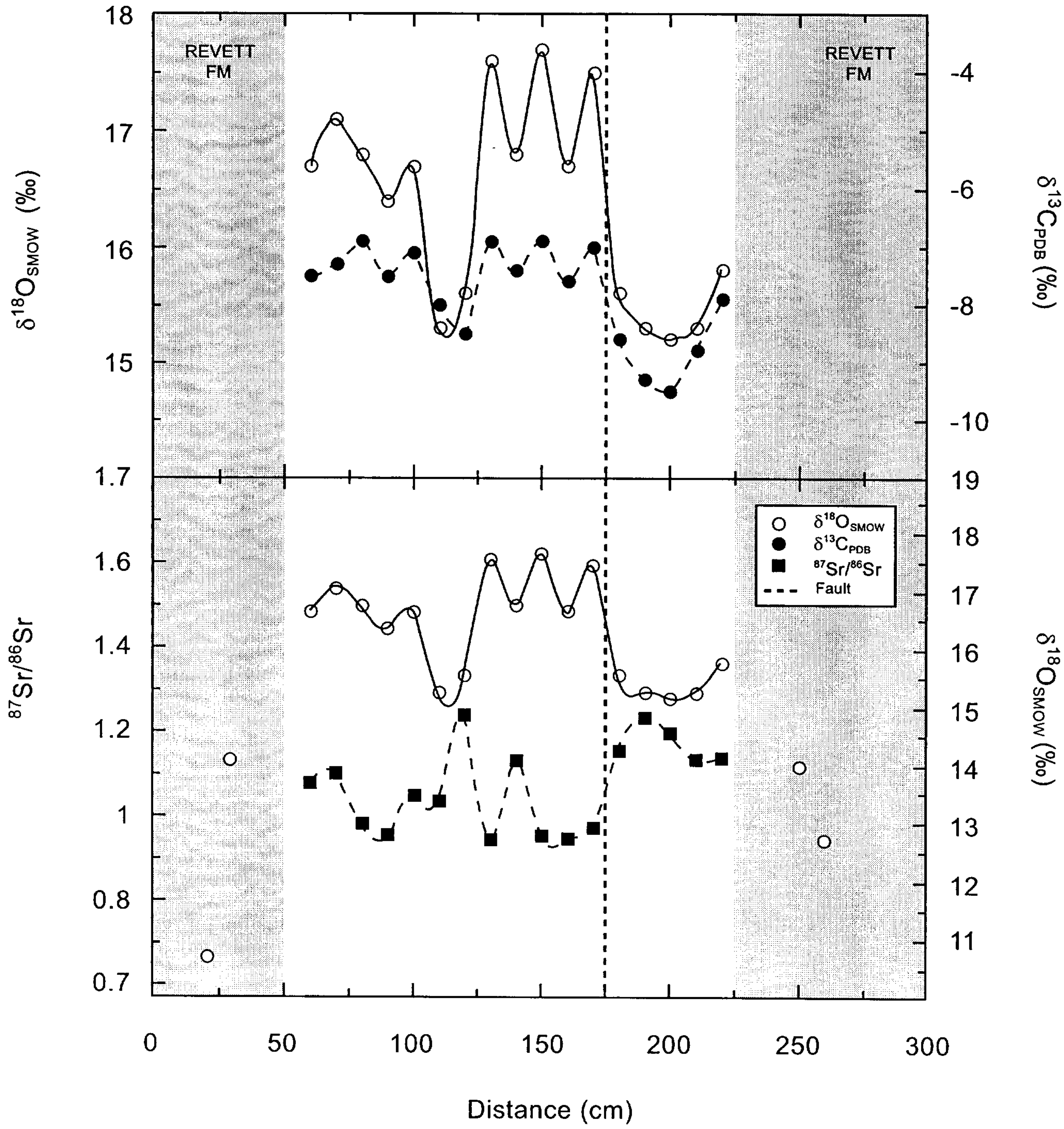

REVETT FM
REVETT FM
δ18OSMOW (‰)
δ13CPDB (‰)
87Sr/86Sr
1/Sr (ppm)
Distance (cm)
δ18OSMOW
δ13CPDB
1/Sr
87Sr/86Sr
18
17
16
15
1.3
1.2
1.1
1
0.9
0.8
0.7
-4
-6
-8
-10
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120

Figure 5



REVETT FM
REVETT FM
18
17
16
15
1.7
1.6
1.4
1.2
1
0.8
0.7
-4
-6
-8
-10
19
18
17
16
15
14
13
12
11
$\delta^{18}O_{SMOW}$ (‰)
$\delta^{13}C_{PDB}$ (‰)
$^{87}Sr/^{86}Sr$
$\delta^{18}O_{SMOW}$ (‰)
$\delta^{18}O_{SMOW}$
$\delta^{13}C_{PDB}$
$^{87}Sr/^{86}Sr$
Fault
0
50
100
150
200
250
300
Distance (cm)

Figure 6

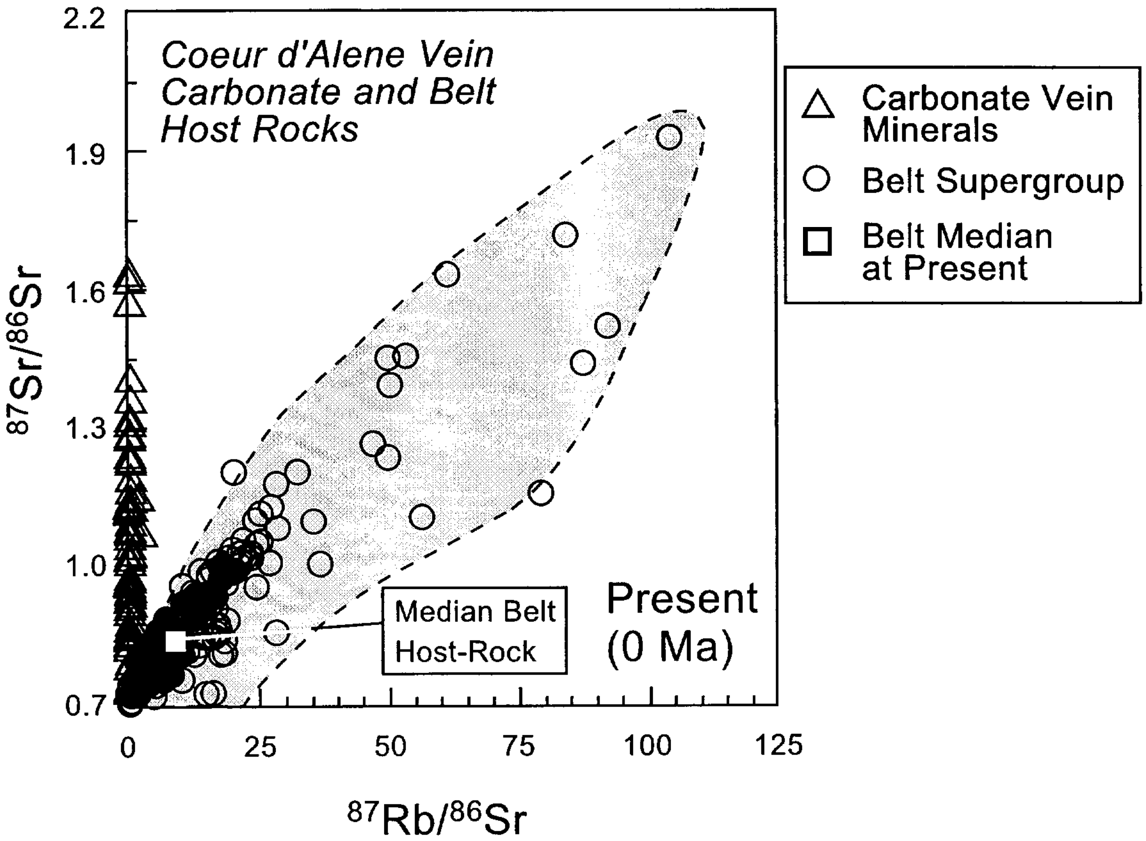

Coeur d'Alene Vein
Carbonate and Belt
Host Rocks
Carbonate Vein Minerals
Belt Supergroup
Belt Median at Present
Median Belt Host-Rock
Present (0 Ma)
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
2.2
1.9
1.6
1.3
1.0
0.7
0
25
50
75
100
125

Figure 7

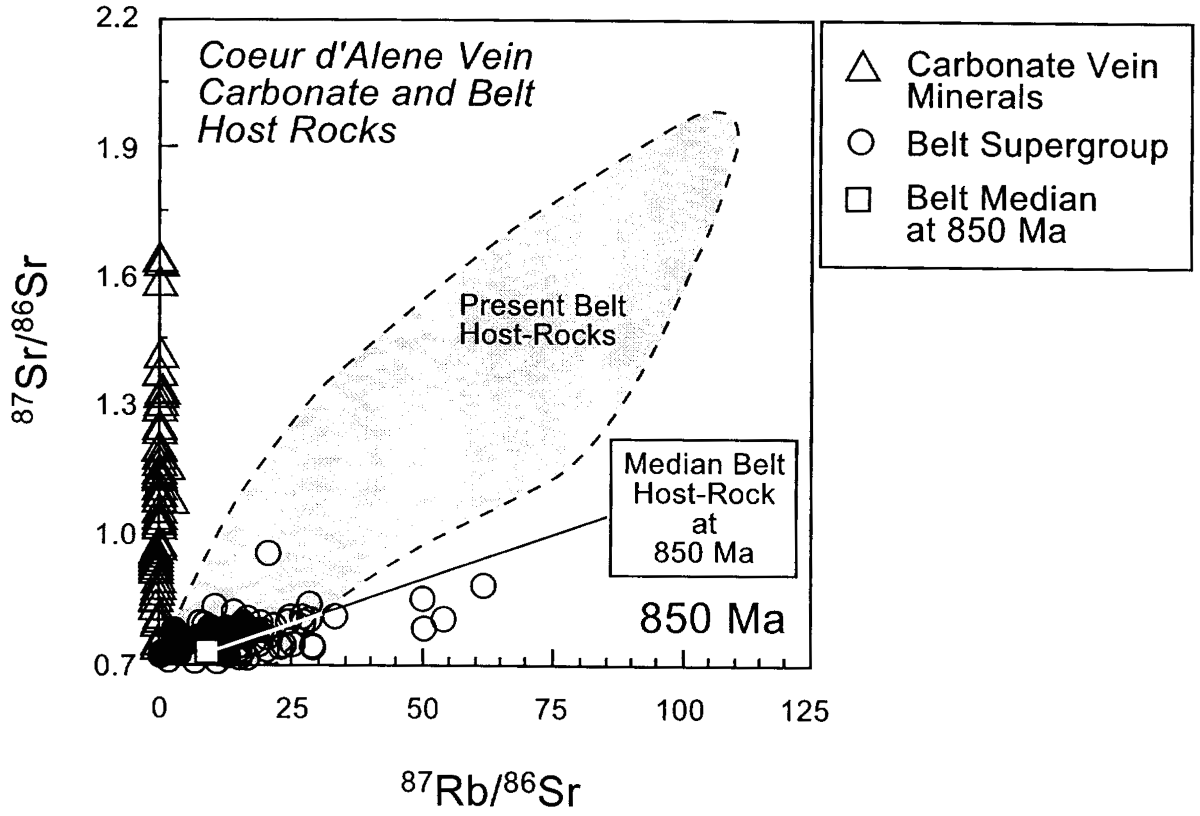
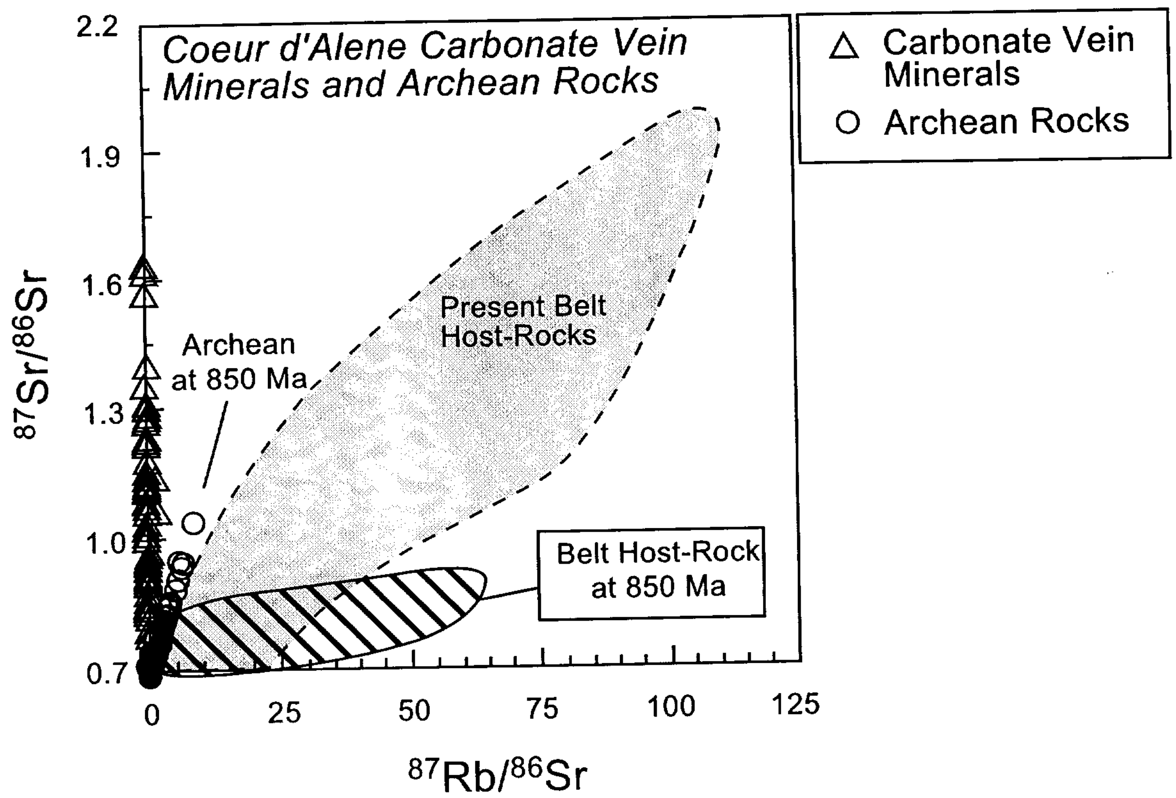

Coeur d'Alene Vein
Carbonate and Belt
Host Rocks
Present Belt
Host-Rocks
Median Belt
Host-Rock
at
850 Ma
850 Ma
2.2
1.9
1.6
1.3
1.0
0.7
0
25
50
75
100
125
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$
Carbonate Vein
Minerals
Belt Supergroup
Belt Median
at 850 Ma

Figure 8



Coeur d'Alene Carbonate Vein Minerals and Archean Rocks
Carbonate Vein Minerals
Archean Rocks
Present Belt Host-Rocks
Archean at 850 Ma
Belt Host-Rock at 850 Ma
2.2
1.9
1.6
1.3
1.0
0.7
0
25
50
75
100
125
$^{87}Sr/^{86}Sr$
$^{87}Rb/^{86}Sr$

Figure 9